भारतीय मानक
Indian Standard

IS 17401 : 2021

काँच रेशा प्रबलित जिप्सम पैनल का प्रयोग करके भवनों का डिज़ाइन व निर्माण — रीति संहिता

Design and Construction of Buildings Using Glass Fibre Reinforced Gypsum Panels — Code of Practice

ICS 91.100.10

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February 2021 **Price Group 14**

Building Limes and Gypsum Products Sectional Committee, CED 04

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Building Limes and Gypsum Products Sectional Committee had been approved by the Civil Engineering Division Council.

Glass fibre reinforced gypsum (GFRG) is a building panel product, made essentially of gypsum plaster, reinforced with glass fibres, and is also known in the industry as Rapidwall. It is manufactured as large light-weight panels, typically 12 m long and 3 m high, with 124 mm thickness and with hollow cavities.

GFRG panels can be manufactured from various types of gypsum. The use of industrial waste gypsum, which is a waste product of the fertilizer industry, being particularly beneficial from the perspective of sustainability being the utilization of waste.

Use of GFRG panels as walls and floor slabs in buildings, with the cavities filled with concrete or appropriate inert material, contribute significantly to sustainability, owing to the resulting savings in the use of high energy-intensive and scarce materials such as cement, steel, sand and water.

GFRG panels can also be used as non-load bearing infill walls (external and internal walls) in conventional RC framed construction, with appropriate connections and installation procedure.

This standard has been formulated based on researched field work to provide guidance in structural design and construction of buildings using GFRG panels. A separate standard, IS 17400 : 2021 'Glass fibre reinforced gypsum panels — Specification' has been formulated for specifications for the product.

In the formulation of this standard, the research and development work done by the Indian Institute of Technology Madras, Chennai and the work done by Building Material and Technology Promotion Council, Ministry of Housing and Urban affairs, Government of India, have been utilized.

The composition of the Committee responsible for the formulation of this standard is given in Annex D.

For the purpose of deciding whether a particular requirement of this standard is complied with the final value, observed or calculated, expressing the result of a test or analysis shall be rounded off in accordance with IS 2 : 1960 'Rules for Rounding off Numerical Values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

DESIGN AND CONSTRUCTION OF BUILDINGS USING GLASS FIBRE REINFORCED GYPSUM PANELS — CODE OF PRACTICE

1 SCOPE

1.1 This standard provides design considerations of Glass fibre reinforced gypsum (GFRG) panels for use in structural design of buildings.

1.2 This standard covers the structural design of vertical members using GFRG panels in buildings up to a maximum of ten storeys or up to 35 m height (from ground level including plinth height and staircase/lift well head room in terrace floor), with the cavities filled with reinforced concrete (partially or wholly), subject to axial compression, compression with out-of-plane bending, and compression with in-plane bending and shear.

1.3 This standard covers the structural design of horizontal members using GFRG panels as flexural members in floors and roofs (flat or sloped) and staircases, with the cavities filled with reinforced concrete (partially or wholly).

1.4 The standard also covers the use of GFRG panels as non-load bearing infill walls (external and internal walls) in RC framed multi-storeyed buildings.

2 REFERENCES

The Indian Standards listed in Annex A contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All the standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent edition of the standards indicated in Annex A.

3 TERMINOLOGY

For the purpose of this standard, the definitions given in, IS 17400, IS 2469 and IS 6461 (Parts 1 to 12) shall generally apply.

4 SYMBOLS

For the purpose of this standard, the following letter symbols shall have the meaning indicated against each, where other symbols are used, they are explained at the appropriate place:

A = Gross cross-sectional area of panels with cavities

A_c = Net area of cross-section of concrete infill

A_G = Net area of cross-section of GFRG panel

a_s = Total area of steel rebars in a panel

D = Depth or width of cross-section

d = Effective depth of cross-section

e = Eccentricity

E_c = Elastic modulus of concrete

E_G = Elastic modulus of GFRG

EI = Flexural rigidity

f_{ck} = Characteristic cube strength of concrete

f_{st} = Stress in steel rebars

f_y = Characteristic strength of steel

M_u = Factored bending moment

M_{uc} = Out-of-plane moment capacity, rib parallel to span

$M_{uc\text{-}perp}$ = Out-of-plane moment capacity, rib perpendicular to span

M_{ud} = Design bending moment capacity

p = Percentage of tension steel

P_u = Factored axial load

P_{uc} = Uni-axial Compressive Strength

P_{ud} = Design axial load capacity

R = Response reduction factor

t = Thickness of panel

T_{uc} = Uni-axial tensile strength

V_u = Factored shear force

V_{uc} = Ultimate shear strength

V_{ud} = Design shear capacity

x_i = Distance from the centre of the panel to the centre of the rebar in each cavity

x_u = Depth of compression zone

γ_f = Partial safety factor for load

γ_m = Partial safety factor for GFRG panel

γ_s = Partial safety factor for reinforcing steel

η = Ratio of infilled cavities to total number of cavities

5 GENERAL REQUIREMENTS

5.1 The design shall satisfy the requirements of IS 456, IS 1905, IS 11447, IS 875 (Parts 1 to 5), IS 1893 (Part 1), IS 4326, IS 15916 and IS 13920, as applicable.

5.2 ‘Cutting drawings’ shall be prepared with clarity, to facilitate cutting at the manufacturing plant, of the various wall or floor panels to appropriate sizes. In the case of wall panels, openings for doors, windows, etc shall be suitably marked in the respective panels. When the panels are cut at the factory in accordance with the cutting drawings, the panels shall be suitably marked on the panel surfaces, to facilitate correct identification, for proper placement during erection at the construction site. The dimensional tolerance allowed for one cut panel is ± 2 mm.

5.3 In constructions using GFRG panels as load bearing structural walling, the walls in the ground floor shall be typically founded on reinforced concrete (RC) plinth beams, in which appropriate starter bars shall be embedded at the locations where the cavities of the panel are to be filled with RC with appropriate lap length in accordance with IS 456. In the case of multi-storeyed buildings. The design and detailing shall ensure proper transfer of base shear due to lateral loading at the interface of the foundation and superstructure. Shear keys may be provided in the RC plinth beams at the GFRG wall cavity locations, suitably reinforced.

5.4 The cavities in the GFRG panels, used as walls or floors, shall be filled, wherever required structurally, with concrete of grade not less than M 20, using maximum nominal size aggregate of 12.5 mm. As this concrete is fully encased in the GFRG panel, the exposure condition may be treated as ‘mild’, in accordance with IS 456. Reinforcing bars, of diameters not less than 8 mm and of grades recommended in IS 456, shall be embedded in the concrete, in accordance with the structural design.

Other cavities shall be filled generally with concrete of minimum grade of M 7.5 or other suitable material (such as quarry dust mixed with minimum 5 percent cement and water to produce a hardened cake). Where safety against intrusion is the concern, filling may be done with M 20 grade of concrete.

5.5 Above the openings for doors and windows, exceeding 1.2 m in width, RC embedded lintels shall be provided.

5.6 Special care shall be taken during construction to ensure proper connections, with concrete filling in the cavities and with appropriate reinforcement detailing, at the junctions between cross walls and at the junctions between walls and floor/roof slabs (in the form of embedded horizontal ties), as indicated in Annex B.

5.7 GFRG panels can also be used for the construction of parapets, staircases, lift wells and balconies, with proper structural design and detailing. If the GFRG panels are used as waist slabs, it is recommended that all the cavities be filled with reinforced concrete. In the case of cantilever projections, such as balconies, suitable RC beams (concealed within GFRG forms) may be designed and detailed, as required.

5.8 The hydrophobic property of GFRG panels sets the need for application of a special primer (primer with strong bonding over GFRG) on the panel surfaces to facilitate rendering and/or painting. This primer shall be applied over the entire exposed panel surfaces, namely, external and internal wall panel surfaces and under-side of the GFRG-RC floor/roof slab (ceiling), as part of the finishing works done on the GFRG building. In addition to providing bonding to the finishing coats, the special primer also enhances the abrasion resistance and hardness of the panels. The suitability of any primer for use with GFRG shall be tested for adhesion as per **6** of IS 101 (Part 5/Sec 2), and hardness as per **4** of IS 101 (Part 5/Sec 1). The tests shall be performed on GFRG panels after coating with primer and subsequent drying.

5.9 In order to ensure durability, suitable water proofing treatment shall be carried out to prevent ingress of rain water at wall corner joints, RC lintel-cum-sunshades, external joints between plinth beam/floor/roof slab and walls, parapet wall, wet areas, like bath, toilet, balcony, open terrace, roof slab, etc.

5.10 The GFRG panels shall be kept in a vertical position and transported in stillages with appropriate tying and stacking arrangements. Cut panels of width up to 2.0 m may be transported in a horizontal position, stacked one on top of the other (up to twelve numbers), with proper tying, for safe vehicular transport.

6 PRODUCT DIMENSIONS AND PROPERTIES

6.1 The GFRG panels used shall conform to IS 17400.

6.1.1 The panels shall be cut to required sizes in the factory or at site using appropriate cutting saw.

6.2 The properties given in this standard are exclusively for the dimensions shown in Figs. 1 and 2. If the panels are manufactured to different dimensions, the properties shall be suitably ascertained by appropriate testing.

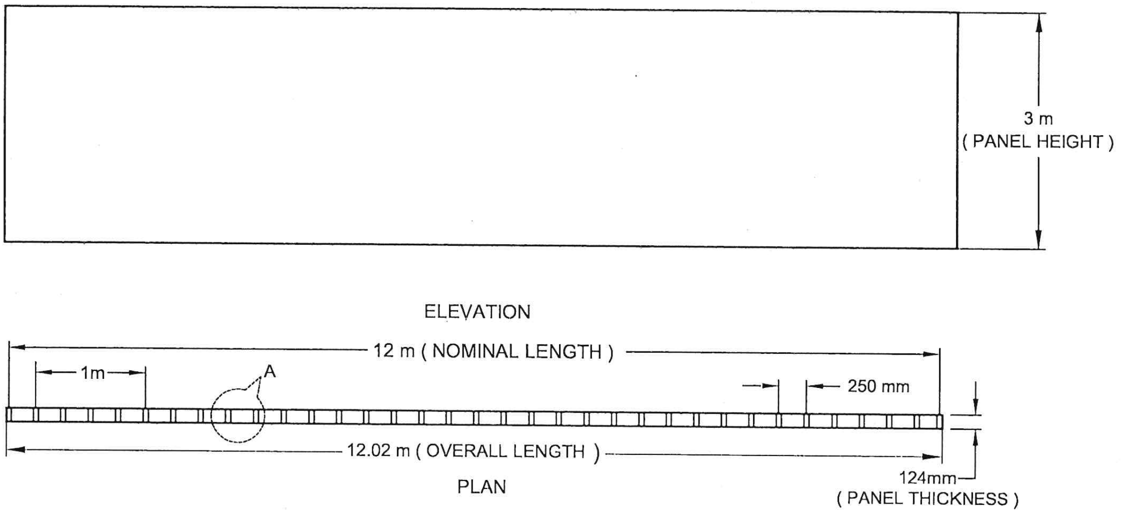


Fig. 1 GFRG Panel-Plan and Elevation

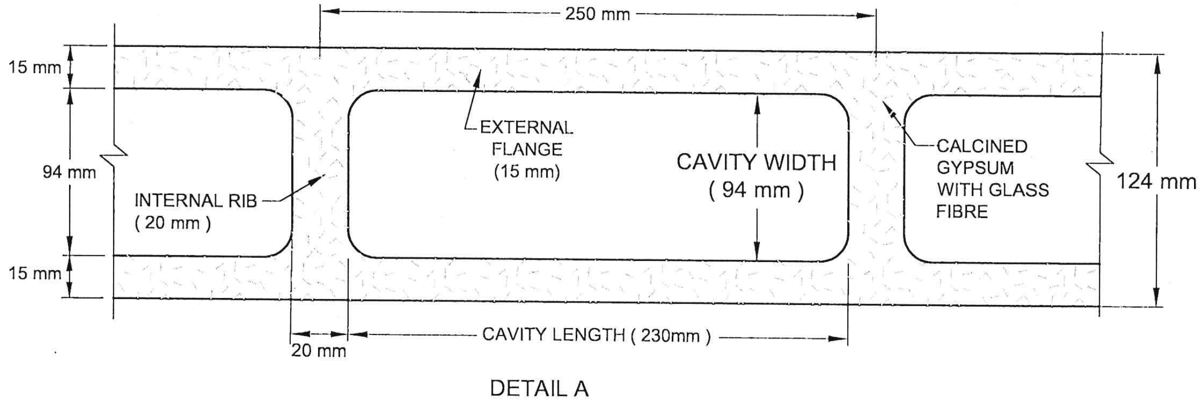


Fig. 2 Cross section of GFRG (Typical Cross-Section and Enlarged View of a Cavity)

6.2.1 The panels used in construction as load-bearing walls and slabs shall comply with the properties given in IS 17400. The characteristic stress-strain curve of GFRG based on uniaxial compression on specimens of size, 520 mm long and 250 mm high, is shown in Fig. 3.

6.2.1.1 On the basis of tests carried out on unfilled panels of size and thickness given in IS 17400, the properties given in Table 1 shall be used.

6.2.1.2 On the basis of tests carried out on panels of size and thickness given in IS 17400, the properties shall be used of GFRG panel filled with M 20 grade concrete in all cavities is as below:

a) Uni-axial compression capacity, P_{uc} (both ends hinged) = 1 310 kN/m;

b) Uni-axial compression capacity, P_{uc} (one end fixed and other end hinged) = 1 360 kN/m; and

c) Ultimate shear capacity, V_{uc} = 61 kN/m.

Table 1 Mechanical Properties of GFRG Panel

(*Clause* 6.2.1.1)

Sl No.	Property	Nominal Value
(1)	(2)	(3)
i)	Modulus of elasticity, E_G	7 500 N/mm^2
ii)	Uni-axial compression capacity, P_{uc}	160 kN/m
iii)	Uni-axial tensile capacity, T_{uc}	34 to 37 kN/m
iv)	Ultimate shear capacity, V_{uc}	21.6 kN/m
v)	Coefficient of Thermal expansion	12 × 10^{-6} mm/mm/°C

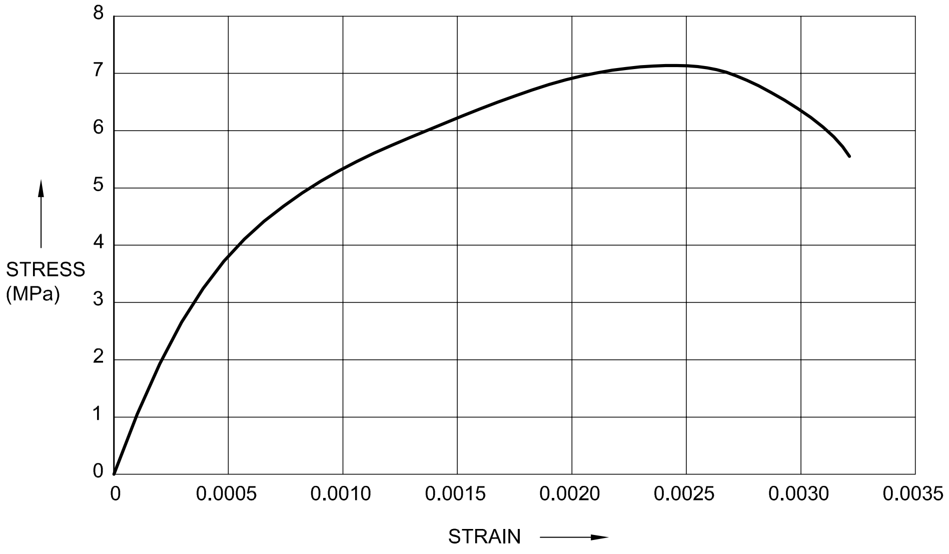


FIG. 3 STRESS–STRAIN CURVE OF GFRG UNFILLED SPECIMEN PRISM UNDER COMPRESSION

6.2.1.3 The nominal value of uni-axial compression capacity and in-plane shear capacity of partially filled GRFG panel with M 20 concrete (both ends restrained) shall be calculated as follows:

$$P_{uc} = (160 + 1200\eta) \text{ kN/m}$$

$$V_{uc} = (21.6 + 38.4\eta) \text{ kN/m}$$

where

$$\eta = \frac{\text{Number of concrete filled cavities in the panel}}{\text{Total number of cavities in the panel}}$$

7 DESIGN PHILOSOPHY

7.1 General

The design capacities given in these guidelines are based on limit states design procedure, considering the ultimate limit state for strength design, treating the 3.0 m high GFRG panel as the unit material, and considering the strength capacity as obtained from test results.

The design should be such that the structure withstands safely all loads as per IS 875 and IS 1893 (Part 1). It shall also satisfy serviceability requirements, such as limitations of deflection and cracking. In general, the structure shall be designed on the basis of the most critical limit state and shall be checked for other limit states.

7.2 Limit States Design

7.2.1 For ensuring the design objectives, the design should be based on the characteristic values of material strengths and applied loads (actions), which take into account the probability of variations in material strength and load. The design values are derived from the characteristic values through the use of partial safety factors, both for material strengths and for loads, for limit states of collapse and serviceability.

7.2.2 *Partial Safety Factors for Load,* γ_f

The design shall account for various combinations of loads acting on the structure simultaneously. The various load combinations and corresponding partial safety factor for loads shall be used as given in IS 456.

For the limit state of serviceability, the values of γ_f are applicable for short-term effects. While assessing long term effects due to creep, the dead load and that part of live load likely to be permanent should be considered.

7.2.3 *Partial Safety Factor for Material,* γ_m

The magnitude of partial safety factor for the material shall take into account the uncertainty related to the material strength. Although GFRG panels are to be manufactured under carefully controlled conditions, it is considered prudent to treat the material like concrete, for which the partial safety factor specified in IS 456 is 1.50. The partial safety factor for the GFRG panel (with and without concrete infill) shall be taken as γ_m = 1.50 in general. The above partial safety factor, γ_m = 1.50 is applicable to situations involving out-of-plane bending where the observed mode of failure is brittle, as well as in-plane bending of RC filled GFRG panels where the mode of failure is expected to be ductile.

In the case of reinforcing steel, the partial safety factor shall be taken as γ_s = 1.15 in all cases, as recommended in IS 456.

While investigating serviceability limit states, the partial safety factor for all materials should be taken as unity.

7.3 Earthquake Resistant Design

7.3.1 Earthquake resistant design shall be carried out in compliance with the requirements of IS 1893 (Part 1). In such design, an important and difficult task is the determination of the response reduction factor, *R*. This is traditionally arrived at, based on the general observed performance of similar buildings during past earthquakes, estimates of general system toughness and the amount of damping present during inelastic response. As the GFRG building constitutes a new type of structure, a reasonable choice of *R* factor can only be made by comparing the GFRG building system with traditional structures, such as reinforced concrete wall building systems for which the response modification factors are already available.

7.3.2 GFRG walls are members with partial interaction, and the ductility of a partially interactive member is generally greater than that of a fully interactive reinforced concrete member. In terms of strength reserve, it is recommended that the safety margin adopted for the design of GFRG walls be at least as large as that adopted for concrete structures. Buildings constructed with GFRG walls may be treated as reinforced concrete shear wall structures and the *R* values are adopted from IS 1893 (Part 1). Hence, the response reduction factor, *R* may be taken as 3.0 for seismic load calculations.

8 AXIAL LOAD CAPACITY

8.1 While assessing the axial load capacity of GFRG panel (under compression), it is important to consider possible eccentricities in loading. A minimum eccentricity (causing out-of-plane bending) shall always be accounted for in the design.

8.2 Minimum Eccentricity

8.2.1 The design of a GFRG wall panel shall take into account the actual eccentricity of the vertical force, subjected to a minimum value of one-sixth of the wall thickness, $t/6$ (that is, 20.7 mm for t = 124 mm).

8.2.2 Additional value of eccentricity shall be considered when out-of-plane bending is explicitly involved (for example, action of local wind effects on an exposed wall panel).

8.3 Axial Compressive Strength

8.3.1 The characteristic values of axial compressive strength of GFRG panel can be obtained from compression test results of the panel for full height panel, subject to various eccentricities of loading (typically, 20 mm, 30 mm, 45 mm) and different boundary conditions; linear interpolation of the results may be assumed. In general, the pinned-pinned condition shall be assumed. For design purposes, the values so obtained should be divided by $\gamma_m = 1.50$.

8.3.2 In the absence of alternate rigorous test data, the values of design strength, P_{ud}, (including partial safety factor), applicable for walls with t = 124 mm, shall be taken, as indicated in **8.3.2.1** for unfilled panels and **8.3.2.2** for filled panels.

8.3.2.1 *Unfilled panels*

The design axial load capacity, P_{ud}, including partial safety factor, of the unfilled GFRG panel may be found from the following equation for all heights of the walls less than 3.0 m (assuming pinned-pinned end conditions).

$$P_{ud} = (68 - 0.9e)$$

where, e is eccentricity in mm and P_{ud} is in kN/m.

8.3.2.2 *Filled panels*

The design axial load capacity, P_{ud} including partial safety factor, of the filled GFRG panel (filled with minimum M 20 grade concrete) may be found from the following equation for all heights of the wall less than 3.0 m (assuming pinned-pinned end conditions):

$$P_{ud} = (600 - 13.75e)$$

where, e is eccentricity in mm and P_{ud} is in kN/m.

The contribution of reinforcing bars in compression shall be ignored.

NOTE — Experimental studies have established that there is no significant enhancement in strength under pure compression due to the presence of rebars, as the failure is caused by buckling of the panel.

9 OUT-OF-PLANE BENDING CAPACITY

9.1 Unfilled GFRG Panels

The out-of-plane design flexural strength of the 124 mm thick GFRG panel without concrete filling shall be as given in Table 2. The bending capacity depends on the orientation of the ribs with respect to the direction of bending. Higher capacity is obtained when the ribs are oriented parallel to the span.

Table 2 Out-of-Plane Design Flexural Capacity of Unfilled GFRG Panel

(*Clause* 9.1)

Sl No.	Design Moment Capacity	*M*ud
i)	For Ribs Parallel to Span	1.4 kNm/m
ii)	For Ribs Perpendicular to Span	0.59 kNm/m

9.2 Filled GFRG Panels

When the cavities are filled with concrete, some enhancement in strength may be expected, provided the ribs are aligned parallel to the span. However, full composite action of GFRG and concrete cannot be mobilized on account of bond slip at the interface. A conservative estimate of the moment capacity may be arrived at by ignoring the contribution of GFRG and considering the action of the concrete beams occupying the cellular cavities (230 mm wide and 94 mm deep), spaced at 250 mm intervals. Accordingly, considering modulus of rupture of concrete as $0.7\sqrt{f_{ck}}$ and applying a partial safety factor of 1.5, the design moment capacity for M 20 concrete may be arrived at as M_{ud} = 2.83 kNm/m.

Further enhancement in capacity may be achieved by embedding and anchoring reinforcing bars in the middle of the cavities, and designing the reinforced concrete beam elements in accordance with requirements of IS 456.

9.3 GFRG Wall Panel Resistance against Wind Loading

The flexural resistance of the GFRG wall panel against wind pressure as per IS 875 (Part 3) shall be checked. One way bending action of the panel (full height of 3 m) may be assumed conservatively, with simply supported end conditions and a pressure co-efficient of unity.

10 SHEAR STRENGTH

10.1 The unit shear strength capacity of the 124 mm thick, 3.0 m high GFRG panel shall be as given in Table 3. The ultimate design shear strength of a GFRG panel shall be obtained by multiplying unit shear capacity as given in Table 3 by the length of the panel.

Table 3 Shear Strength of GFRG Panel as Vertical Walls

(*Clauses* 10.1 *and* 10.2)

Sl No.	Application	Design Shear Capacity, V_{ud} kN/m
(1)	(2)	(3)
i)	Unfilled GFRG panel	14.4
ii)	GFRG panel filled with M 20 MPa concrete	40.0
iii)	GFRG panel partially filled with M 20 concrete	$14.4 + 25.6\eta$

10.2 In a multi-storeyed construction, using GFRG wall panels as load bearing construction, different walls shall be subjected to different shear forces, at the storey level under consideration. Longer walls, which are stiffer, attract large lateral shear. The maximum length of an individual shear wall segment may be limited to 3.5 m in the finite element model used for analysis under factored loads. The average value of factored shear force calculated for all walls in any one direction at any storey level shall not exceed the value indicated in Table 3. In a few walls, some local increase (up to 20 percent) in shear capacity may be permitted, provided the average value for all walls (combined) is within the prescribed limit.

10.3 In wall construction for multi-storeyed buildings, all cavities shall be filled with concrete (of grade not less than M 20) and reinforced appropriately. One cavity in each wall may be left unfilled initially for electrical/cabling purposes, and filled subsequently with M 20 grade concrete. The rebars shall be provided for the full height in the cavities of the concrete-filled GFRG panels, and appropriately lapped (with lap lengths as specified in IS 456) wherever required. At the interface with the foundation plinth beam, starter bars should be provided in each cell embedded in concrete (of strength not less than 20 MPa) for a height of not less than 450 mm. In the case of tall buildings where high base shear is expected to be transmitted, it is desirable to provide appropriate keys in the plinth beam to provide for improved shear transfer.

11 IN-PLANE BENDING CAPACITY

11.1 General

11.1.1 GFRG panels may also be used as walls transferring lateral loads, resisting axial force (*P*), lateral in-plane shear force (*V*) and in-plane bending moment (*M*). Such wall panels shall be filled with concrete and reinforced with steel.

11.1.2 The in-plane bending capacity of the walls depends on its length, the reinforcement provided, as well as the level of axial load and lateral shear. The design in-plane bending capacity, M_{ud} and its relationship with the design axial load capacity, P_{ud} is described by means of a P_{ud}-M_{ud} interaction diagram (*see* **11.2**). The values of M_{ud} increases with the length of the wall. However, experimental studies of GFRG panels subjected to lateral loading have shown that failure is initiated by vertical cracking caused by shear failure of the GFRG skin. Following such vertical cracking, the wall segments separated by the vertical cracks tend to behave independently, although their deformations at the top and bottom are governed by the corresponding deformations in the connecting floor diaphragm. For all practical purposes, the in-plane bending capacity shall be limited by the corresponding shear capacity. Longer shear walls tend to attract larger lateral loads and will form vertical shear cracks in the middle region, causing a further redistribution of forces, and possible further vertical shear cracking.

Under factored lateral loads (earthquake or wind), in the finite element model, the long walls should be suitably segmented such that no segment exceeds 3.5 m in length. Also, while modelling, care should be taken to consider T, L and I-shaped flanged sections as being made up of separate rectangular segments with no shear transfer between them.

Tests have shown that providing two vertical reinforcing bar in each cavity generates improved performance than a single reinforcing bar.

11.2 Basic Design Procedure for generating P_{ud}–M_{ud} Interaction Diagram

Generation of the interaction diagram of a typical GFRG panel shall be carried out based on the procedure given in Annex C.

11.3 Design Charts Axial Load

Moment interaction diagrams (design charts), for various wall lengths, varying from 1.0 m to 3.5 m with increments of 0.25 m, for one or two rebars various bar diameters (8 to 18 mm) of Fe 415 and Fe 500 grade steel in each cavity, and M 20 and M 25 grade concrete, are given in Annex C may be used for design.

11.4 For low rise GFRG buildings (up to three storeys), reinforcing bars may be provided where required, but in no case, more than three adjoining cavities shall remain unreinforced. Single reinforcing bars of suitable diameter (not less than 8 mm), may be used in such low-rise buildings. Such reinforced cavities need to be filled with M 20 grade concrete. It is desirable to fill all other cavities with plain concrete of grade not lower than M 7.5 or quarry dust stabilized with minimum 5 percent cement and water.

12 DESIGN OF FLOOR/ROOF SLAB

12.1 GFRG panels, with ribs aligned in the direction of bending, shall be designed as a one-way slab system, with the cavities suitably reinforced, as shown in Fig. 4.

12.2 GFRG-RC slab systems may be used efficiently in floor slabs and roof slabs. The ribs should be oriented along the shorter span, supported on GFRG wall panels. Although this is a composite system comprising GFRG panel and cast *in-situ* reinforced concrete, for convenience in design, the contribution of GFRG panel towards the flexural strength may be ignored and the GFRG panel can be treated as lost formwork. RC concealed beams, provided by filling cavities at regular intervals (typically, every third cavity or every alternate cavity, if required) and suitably reinforced, combined with a screed concrete of thickness not less than 50 mm, as shown in Fig. 4, provide a flanged-beam action. For the roof slab, the thickness of screed shall be at least 60 mm. One-way slab action may be assumed for strength and deflection check, considering T-beam action of the embedded beams. In the screed concrete, suitable welded wire fabric (of required gauge and spacing) shall be provided. Suitable cover blocks at 750 mm spacing in both directions shall be given. The design of reinforcement in the concealed beams shall conform to the requirements of IS 456. Such slabs can be conveniently designed up to spans of 5 m. For commercial or public buildings with high imposed load, the maximum clear span may be limited to 4 m.

12.3 For floor/roof slab with larger spans and/or high imposed loads, or in balconies, etc, one or more intermediate supporting RC beams may be provided (concealed inside GFRG forms), with sufficient depth protruding below the soffit of the GFRG-RC slab (typically 124 mm below), in a direction perpendicular to the ribs in the GFRG panel. The RC beam shall be suitably designed and detailed, as indicated in Fig. 5, in accordance with IS 456.

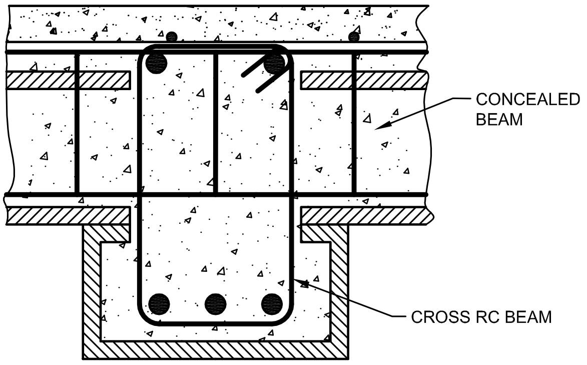


Fig. 5 GFRG-RC Composite Intermediate Beam (Where Required)

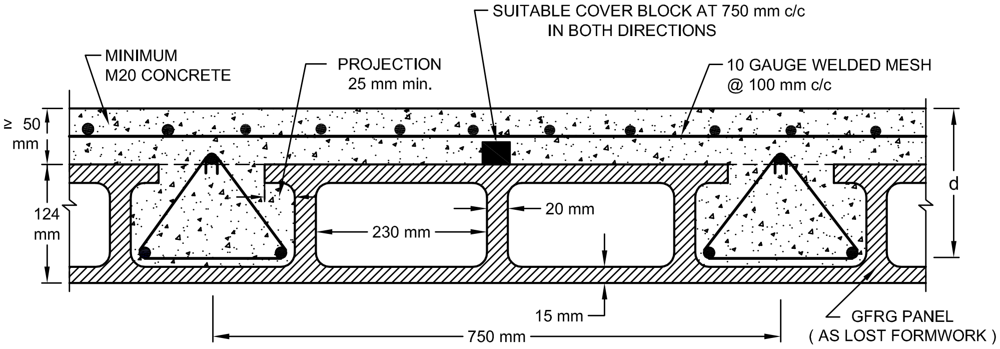

SUITABLE COVER BLOCK AT 750 mm c/c IN BOTH DIRECTIONS
MINIMUM M20 CONCRETE
PROJECTION 25 mm min.
10 GAUGE WELDED MESH @ 100 mm c/c
≥ 50 mm
124 mm
230 mm
20 mm
d
15 mm
750 mm
GFRG PANEL (AS LOST FORMWORK)

Fig. 4 Typical Cross-Section of GFRG-RC Composite Slab (with Concealed RC Beams)

12.4 When the top flange of a cavity of the panel is cut longitudinally (for providing the embedded beam), it shall be ensured that the cut flanges project 25 mm on either side, as shown in Fig. 4 and Fig. 5, to ensure proper integrity of the system.

12.5 For roof slab, minimum of 60 mm thick screed concrete shall be provided. Special care shall be taken while concreting the roof slab, to ensure proper compaction and to render the concrete impermeable.

12.6 Clear cover, not less than 15 mm, shall be provided to all reinforcement adjoining GFRG side and bottom forms, in the GFRG-RC slab and beam system.

12.7 In GFRG floor and roof slabs, jointing of the GFRG panel, where required, shall be treated as described in **B-12**.

12.8 Solid RC slabs, designed according to IS 456, may also be used for GFRG buildings, in lieu of GFRG-RC slabs. RC columns and beams, suitably designed, may also be provided wherever necessary.

13 GFRG PANEL AS PITCHED (SLOPED) ROOFING ELEMENT

Unfilled GFRG panels may be used as pitched roofs for single storeyed small span buildings (typically for affordable mass housing for single separate units). Nominal filling with reinforcement shall be provided at eaves and ridge locations, as shown in Fig. 6. Additional tie down system shall be provided through the roof and wall panel cavities (typically using 8 mm reinforcing bars, which are tied to the starter bars in the RC plinth beam) with maximum spacing of 1.25 m and concrete infilled, for resistance against lateral loads, as illustrated in **B-13**.

Appropriate waterproofing treatment for pitched roofing panel top and eaves sides shall be provided.

14 GFRG PANEL AS INFILL WALL IN RC FRAMED CONSTRUCTION

14.1 The GFRG wall panel may be used as external and internal infill walls in conventional RC multi-storeyed framed construction. The analysis and design of RC beams and columns in the moment resisting frame shall be done as per conventional practice and shall comply with IS 456, IS 1893 (Part 1), IS 875 and other relevant codes.

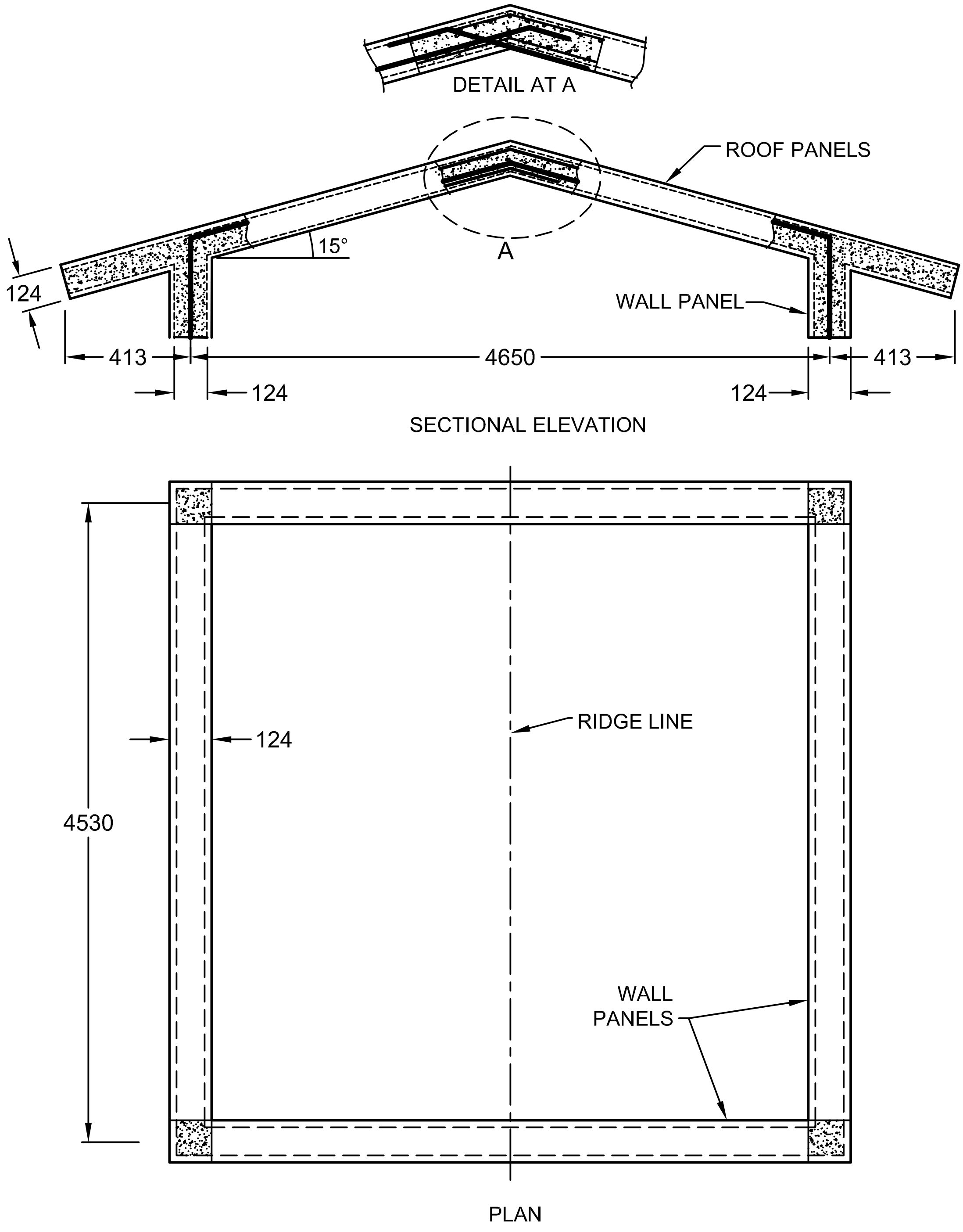
14.2 Installation of GFRG infill walls shall be carefully planned, ensuring adequate wall connectivity with the RC beams at top and bottom through dowel action.

14.3 External walls, exposed to wind, shall be suitably designed to resist the out-of-plane bending, without axial load (other than self-weight). The cavities shall be suitably infilled with required reinforcement and M 20 grade concrete. Dowels shall be designed to resist the lateral out-of-plane shear.

14.4 For internal walls, not exposed to wind, the infilling of cavities with RC needs to be done at minimum 1.25 m spacing, with M 20 concrete and one 10 mm reinforcing bar of Fe 415 or Fe 500, anchored at least 150 mm at bottom and top, to ensure dowel action.

14.5 Other empty cavities shall be infilled with concrete of minimum grade of M 7.5 or other suitable material (such as quarry dust mixed with minimum 5 percent cement mixed dry and infilled and required water poured to produce a hardened cake), as per **5.4**.

14.6 If there is discontinuity of infill wall, it is mandatory to check provisions of soft storey as given in IS 1893 (Part 1) and suitable additional reinforcement may be provided in the RC columns.



All dimensions are in mm

FIG. 6 TYPICAL UNFILLED GFRG PITCHED ROOF

ANNEX A

(*Clause* 2)

LIST OF REFERRED INDIAN STANDARDS

IS No.	*Title*
101	Methods of sampling and test for paints, varnishes and related products:
(Part 5/Sec 1) : 1988	Mechanical tests on paints films — Section 1 Hardness tests (*third revision*)
(Part 5/Sec 2) : 1988	Mechanical tests on paint films, Section 2 Flexibility and adhesion (*third revision*)
456 : 2000	Code of practice for plain and reinforced concrete (*fourth revision*)
875	Code of practice for design loads (other than earthquakes) for buildings and structures:
(Part 1) : 1987	Part 1 Dead loads — Unit weight of building materials and stored materials (*second revision*)
(Part 2) : 1987	Part 2 Imposed loads (*second revision*)
(Part 3) : 2015	Part 3 Wind loads (*third revision*)
(Part 4) : 1987	Part 4 Snow loads (*second revision*)
(Part 5) : 1987	Part 5 Special loads and load combination (*second revision*)
1893 (Part 1) : 2016	Criteria for earthquake resistant design of structures: Part 1 General provisions and buildings (*sixth revision*)
1905 : 1987	Code of practice for structural use of unreinforced masonry (*third revision*)
2469 : 1976	Glossary of terms relating to gypsum (*first revision*)
4326 : 2013	Code of practice for earthquake resistant design and construction of buildings (*third revision*)
6461 (Part 1) : 1972	Glossary of terms relating to cement concrete: Part 1 concrete aggregates
(Part 2) : 1972	Part 2 materials (other than cement and aggregate)
(Part 3) : 1972	Part 3 concrete reinforcement
(Part 4) : 1972	Part 4 types of concrete
(Part 5) : 1972	Part 5 formwork for concrete
(Part 6) : 1972	Part 6 equipment, tools and plant
(Part 7) : 1973	Part 7 mixing, laying, compaction, curing and other construction aspects
(Part 8) : 1973	Part 8 properties of concrete
(Part 9) : 1973	Part 9 structural aspects
(Part 10) : 1973	Part 10 tests and testing apparatus
(Part 11) : 1973	Part 11 prestressed concrete
(Part 12) : 1973	Part 12 miscellaneous
11447 : 1985	Code of practice for construction with large panel prefabricates
13920 : 2016	Code of practice for ductile design and detailing of reinforced concrete structures subjected to seismic loads (*first revision*)
15916 : 2020	Code of practice for building design and erection using prefabricated concrete (*first revision*)
17400 : 2021	Glass fibre reinforced gypsum panels — Specification

ANNEX B

(*Clauses* 5.6, 12.7 *and* 13)

STRUCTURAL DETAILING OF GFRG PANEL BUILDINGS

B-1 CONNECTION BETWEEN GFRG WALLS AND FOUNDATION

B-1.1 All GFRG wall panels at the ground floor shall be erected over a network of RC plinth beams supported on suitable foundation. Starter bars shall be embedded in the RC plinth beams, at precise locations where the cavities are to be filled with reinforced concrete, with appropriate lap length (*see* Fig. 7). In the case of multi-storeyed buildings, where the base shear due to lateral loading (wind or earthquake) is required to be transferred to the foundation, appropriate detailing such as provision of shear keys at the starter bar locations, shall be provided.

B-1.2 For constructing an additional GFRG floor above an existing RC building, connectivity between GFRG wall and the existing floor can be achieved by proper detailing (insertion of starter bars with proper anchorage) as shown in Fig. 8. If the existing roof slab does not have sufficient depth for anchorage, an additional RC beam may be constructed above the roof before erecting the GFRG walls.

For erection of panel over foundation plinth beam, *see* Fig. 9.

B-1.3 In the connection between the cross-walls, adjacent faces of the walls have to be cut open and the adjoining cavities shall be infilled with concrete to have a monolithic connection between them. Steel links shall be provided at the top and bottom of the adjoining wall panels as shown in Fig. 10.

For connection of GFRG-RC beam for long span floors, *see* Fig. 11.

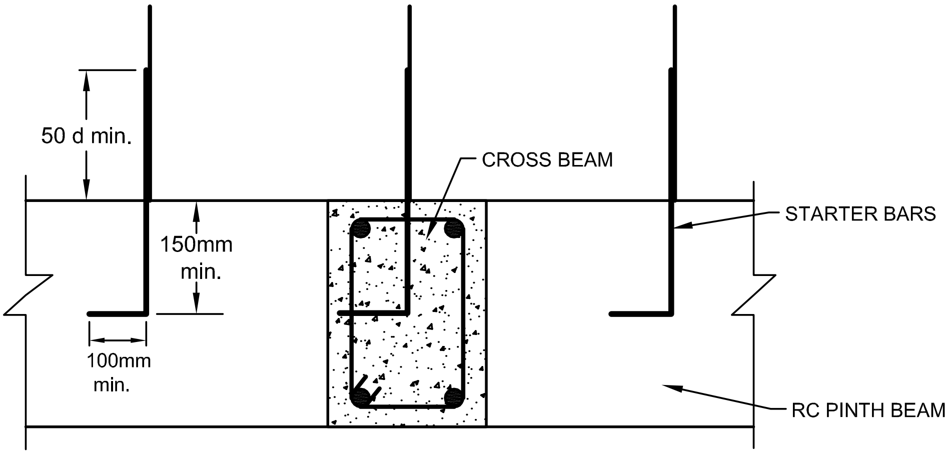


Fig. 7 Provision of Starter Bars in RC Plinth Beams for the Erection of GFRG Panels

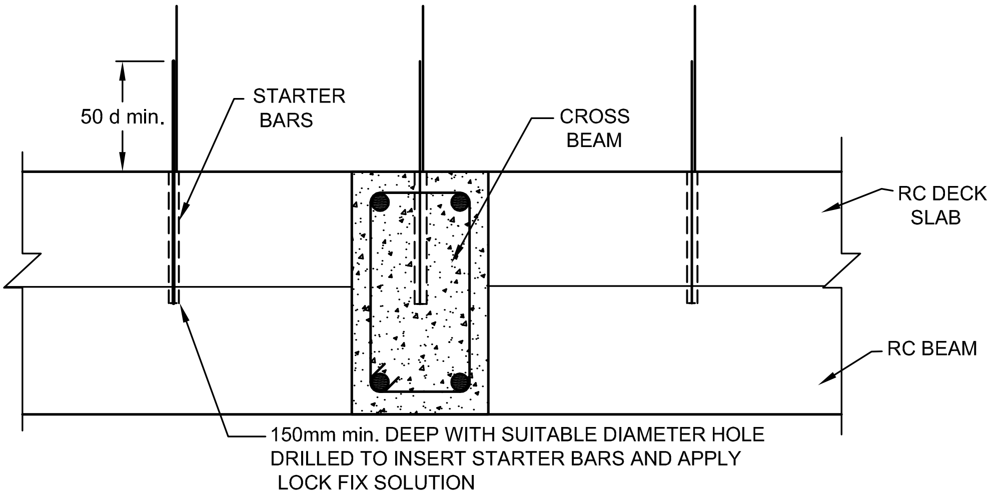

50 d min.
STARTER BARS
CROSS BEAM
RC DECK SLAB
RC BEAM
150mm min. DEEP WITH SUITABLE DIAMETER HOLE DRILLED TO INSERT STARTER BARS AND APPLY LOCK FIX SOLUTION

Fig. 8 Starter Bars in Case of an Existing RC Floor/Roof Slab

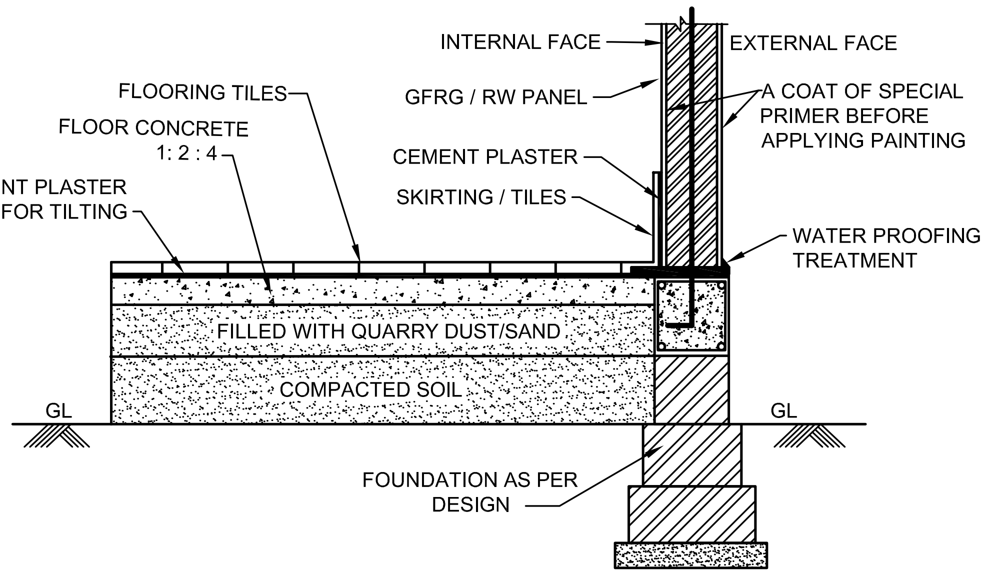
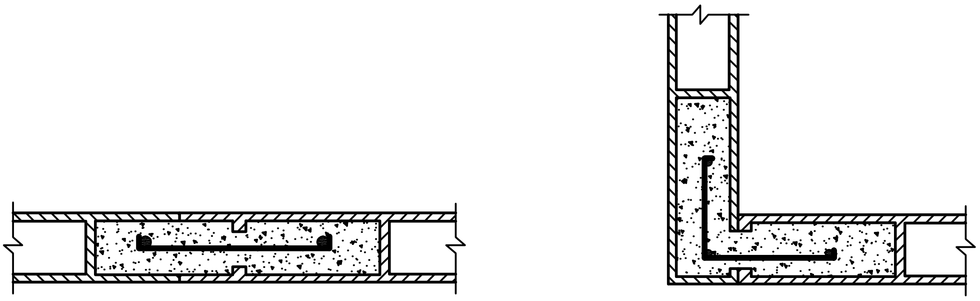
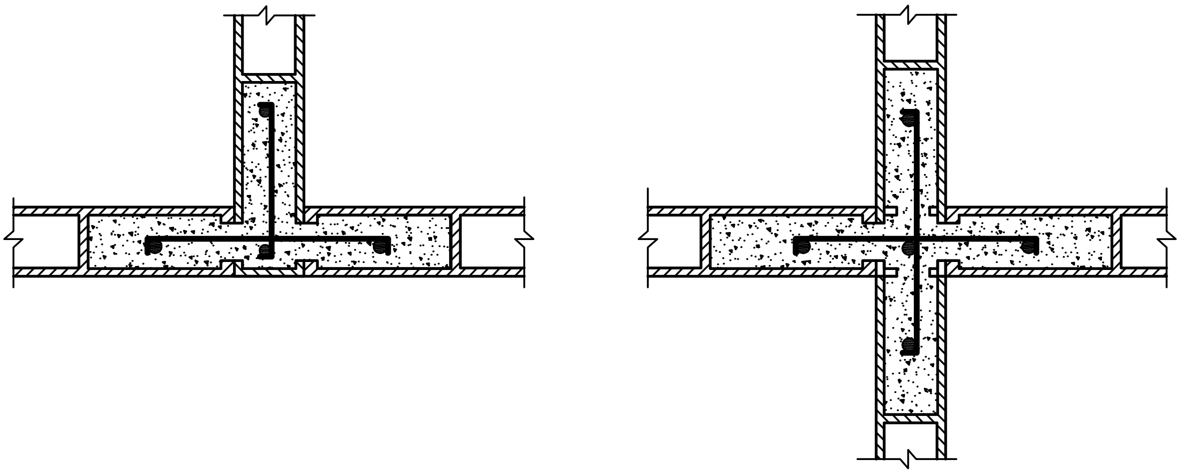


Fig. 9 Foundation, Basement, Plinth Beam and Start-up Bars for Erection of GFRG Panels



10A HORIZONTAL WALL JOINT

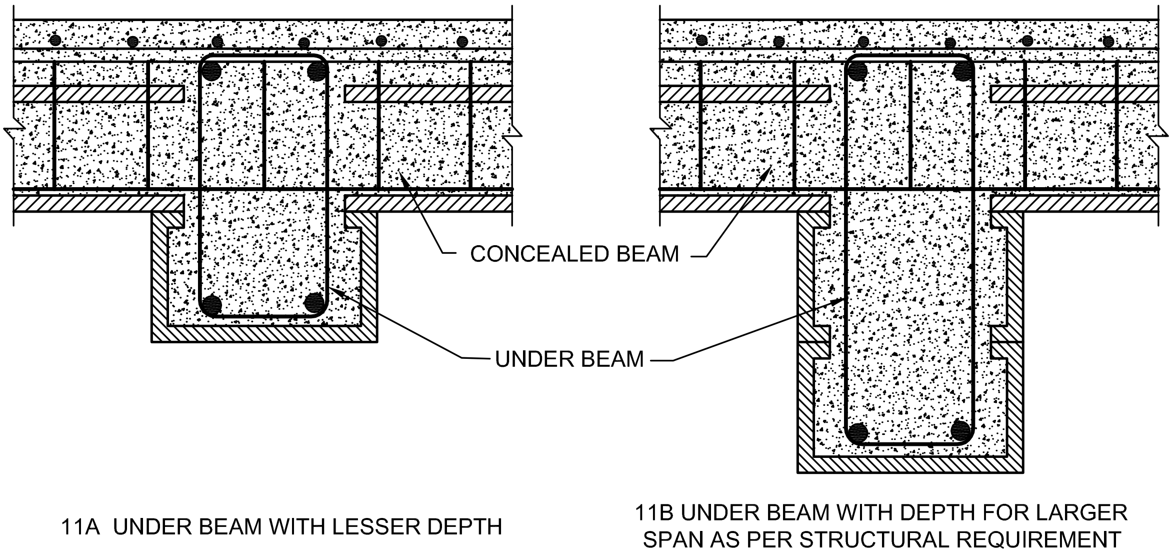
10B "L" WALL CORNER JOINT



10C "T" WALL CORNER JOINT

10D 4-WAY WALL CORNER JOINT

Fig. 10 Typical Wall Joints



11A UNDER BEAM WITH LESSER DEPTH

11B UNDER BEAM WITH DEPTH FOR LARGER SPAN AS PER STRUCTURAL REQUIREMENT

FIG. 11 GFRG-RC COMPOSITE EMBEDDED BEAM FOR LONG SPAN FLOORS

B-2 For external doors and windows with RC sunshade, it is mandatory to provide embedded RC lintel-cum-sunshade with a minimum of 250 mm bearing on either sides with suitable reinforcement including stirrups and adequate anchorage for proper connectivity between lintel, sunshade and vertical wall provided (*see* Fig. 12 and Fig. 13).

B-3 Proper connectivity should be provided when using GFRG panel as waist slab of stair case, provided with both mid landing and floor landing under beams as per the structural design (*see* Figs. 14A and 14B Fig. 15 gives cross-section of GFRG lift well.).

B-4 Proper connectivity for sunken floor slab, shall be provided between the floor slab and vertical walls for bath/toilets, for providing sanitary and water piping in GFRG buildings (*see* Fig. 16).

B-5 Figure 17 shows longitudinal sectional view of wall showing vertical reinforcement details. A minimum clear cover of 25 mm shall be provided for the vertical rebars, whenever two rebars are to be provided in the cavities of the panel, as per the structural design.

B-6 Not more than one cavity be left unfilled in a wall (whether external or internal) for electrical cabling or other piping works. It is mandatory to seal off such embedded water pipes or rain water drainage/sanitary piping joints inside the GFRG panel cavity before infill or pour of concrete, using water resistant sealant.

B-7 Primer shall be applied on GFRG wall panels for external, internal walls and ceiling, before painting or providing any thin layer of rendering for luxurious smooth finish, or to rectify any dent or damage caused by handling of panel during its erection. This shall be applied either by spraying or by roller method after the construction of the super structure, before rendering and painting. The primer application is mandatory before rendering. If rendering is required to be done, it may be over the primer, using approved water resistant rendering compound for external wall surface and wet areas. The calcined gypsum based wall plaster can be used for internal wall surface including the internal corner joints and ceiling.

B-8 Structural design of GFRG panel buildings up to 10 storeys shall be carried out as per the provisions given in this standard using GFRG panel in combination with RC as a load bearing structure.

B-9 GFRG floor/roof slab panel shall have 40 mm bearing over the supporting vertical walls all around, as shown in Fig. 18 and 19.

B-10 Embedded horizontal RC tie beam 94 mm × 200 mm shall be provided on the top of all the walls and in all floors, for GFRG buildings more than four floors, as illustrated in Fig. 18 and 19. This is to provide adequate structural integrity to the building, in line with the design requirements for safety against progressive collapse as per IS 15916. Proper connectivity between the embedded horizontal RC tie beam, RC concealed beams in slabs, concrete RC screed and vertical rods in the GFRG panel wall is required to ensure integral connection between the floor/roof slab and the walling system. The embedded tie beam shall also be provided for walls that are more than 3 m in height, just below the top of the 3 m high wall panel, with the additional height of panel on top. Vertical reinforcing bars in the wall panel cavities shall continue through the entire wall height.

B-11 Embedded horizontal tie beam can be avoided for buildings up to 4 floors (G + 3). In lieu of this, it shall be required to provide horizontal tie connection consisting of 8 number of horizontal reinforcing bars at top and bottom 150 mm apart (with 6 mm links at 250 mm centre-to-centre spacing) all around at the slab-wall junction. This is in conformity with IS 15916. For ease of construction, this tie cage may be assembled in advance and lowered in place. The reinforcing bars shall be additionally tied to all the vertical bars in the wall cavities. It is also necessary to tie the top reinforcing bars of embedded beams in the slab to the top horizontal tie reinforming bars, as illustrated in Figs. 20 and 21.

On the other two sides of slabs where there are no concealed beams, C anchorage of 8 number of reinforcing bars with L angle between top reinforcing bars of adjoining concealed beams on either sides shall be tied to the vertical reinforcing bars at minimum of 750 mm spacing as illustrated in Figs. 22 and 23.

In case of the above option is not provided, 200 mm deep × 94 mm wide embedded RC tie beam on top of all the walls shall be provided as per **B-10**.

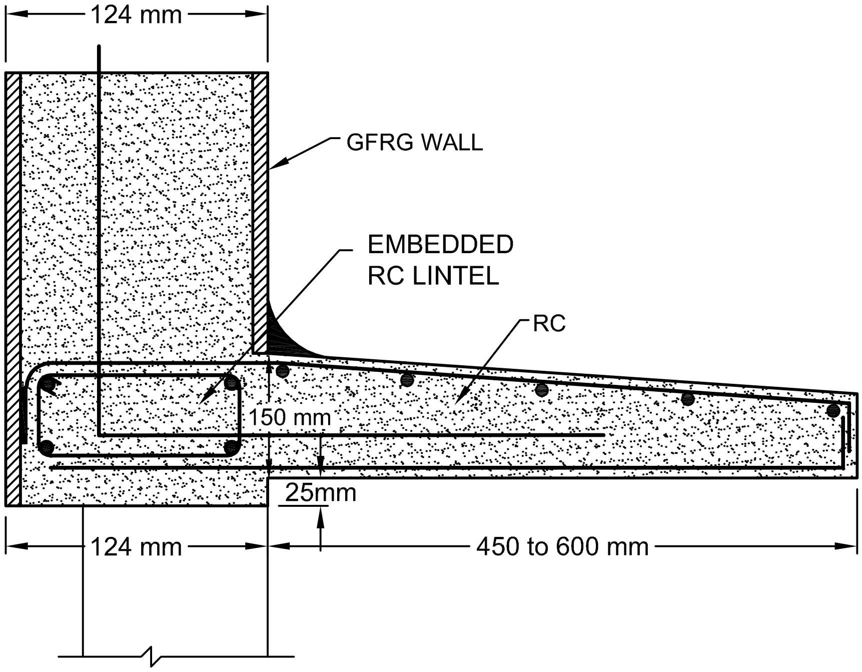


FIG. 12 CONNECTIVITY BETWEEN LINTEL, SUNSHADE AND GFRG PANEL

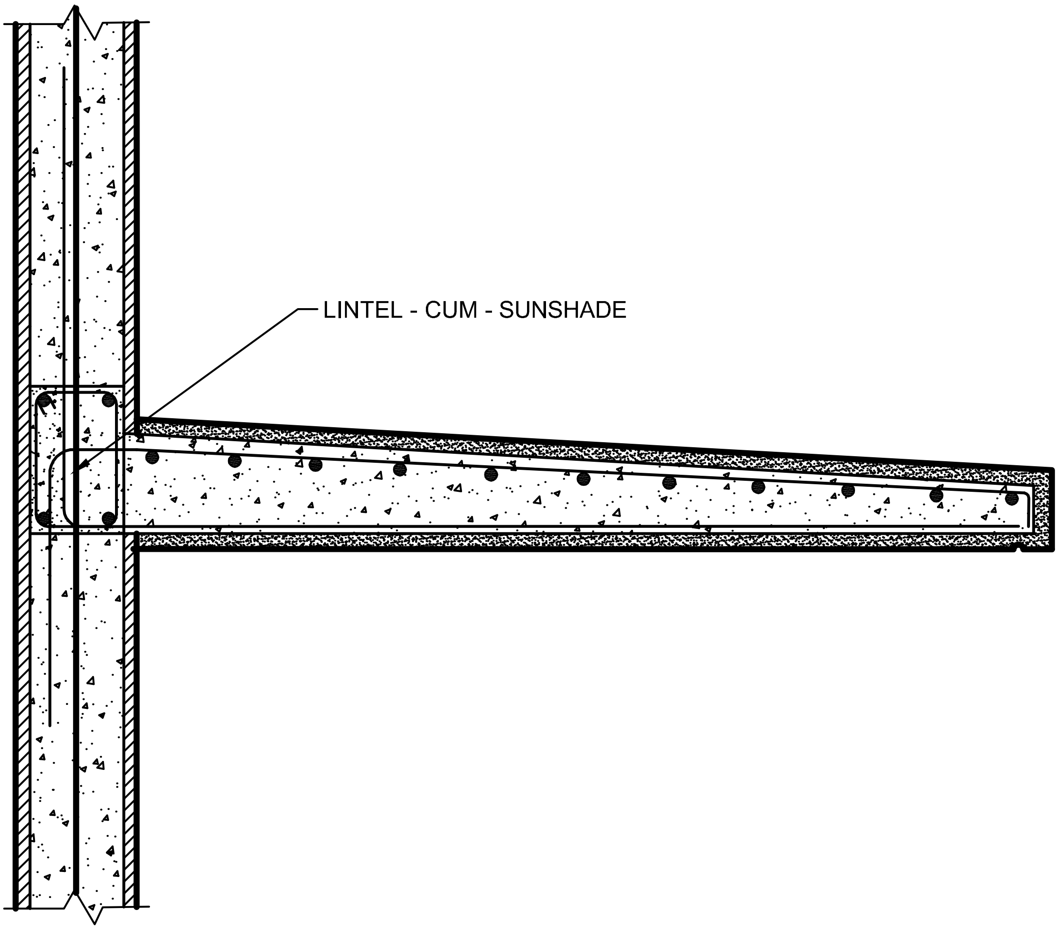
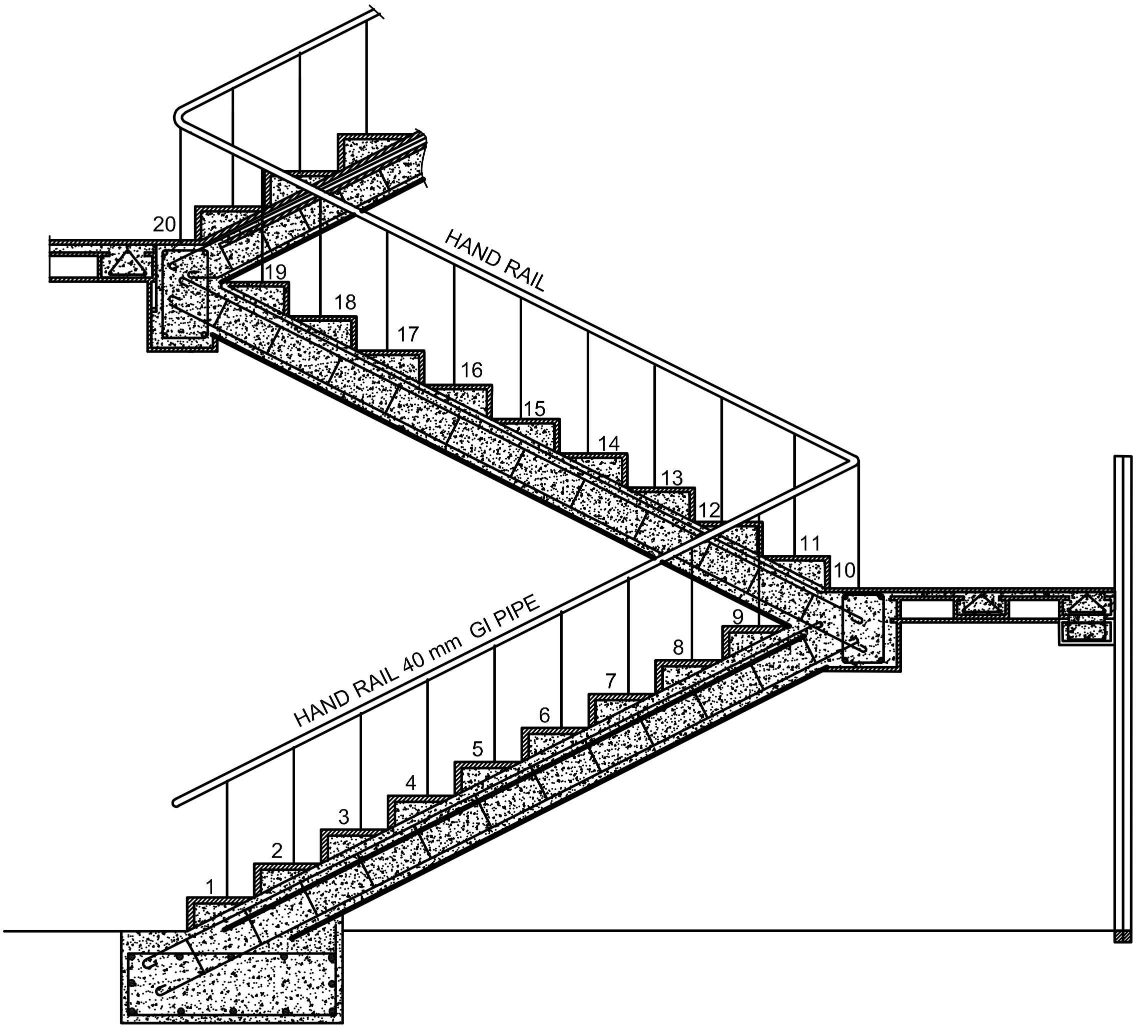
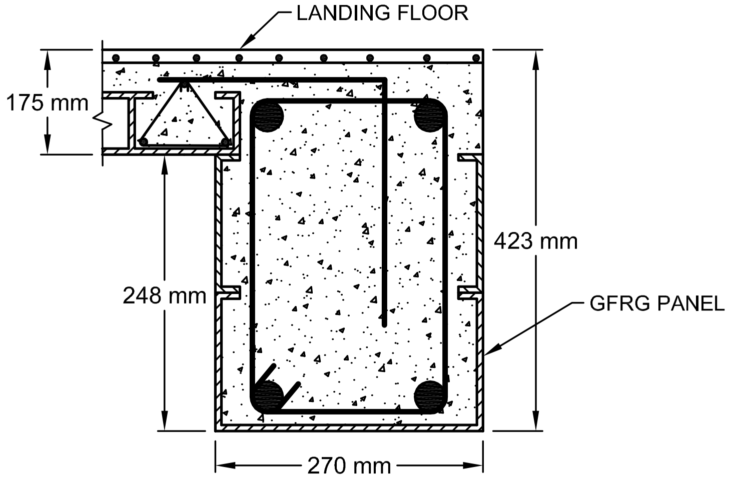


FIG. 13 LINTEL, SUNSHADE AND GFRG PANEL WALL



14 A CROSS - SECTION OF STAIRCASE



14 B STAIRCASE FLOOR LANDING BEAM

Fig. 14 Staircase Using GFRG Panels

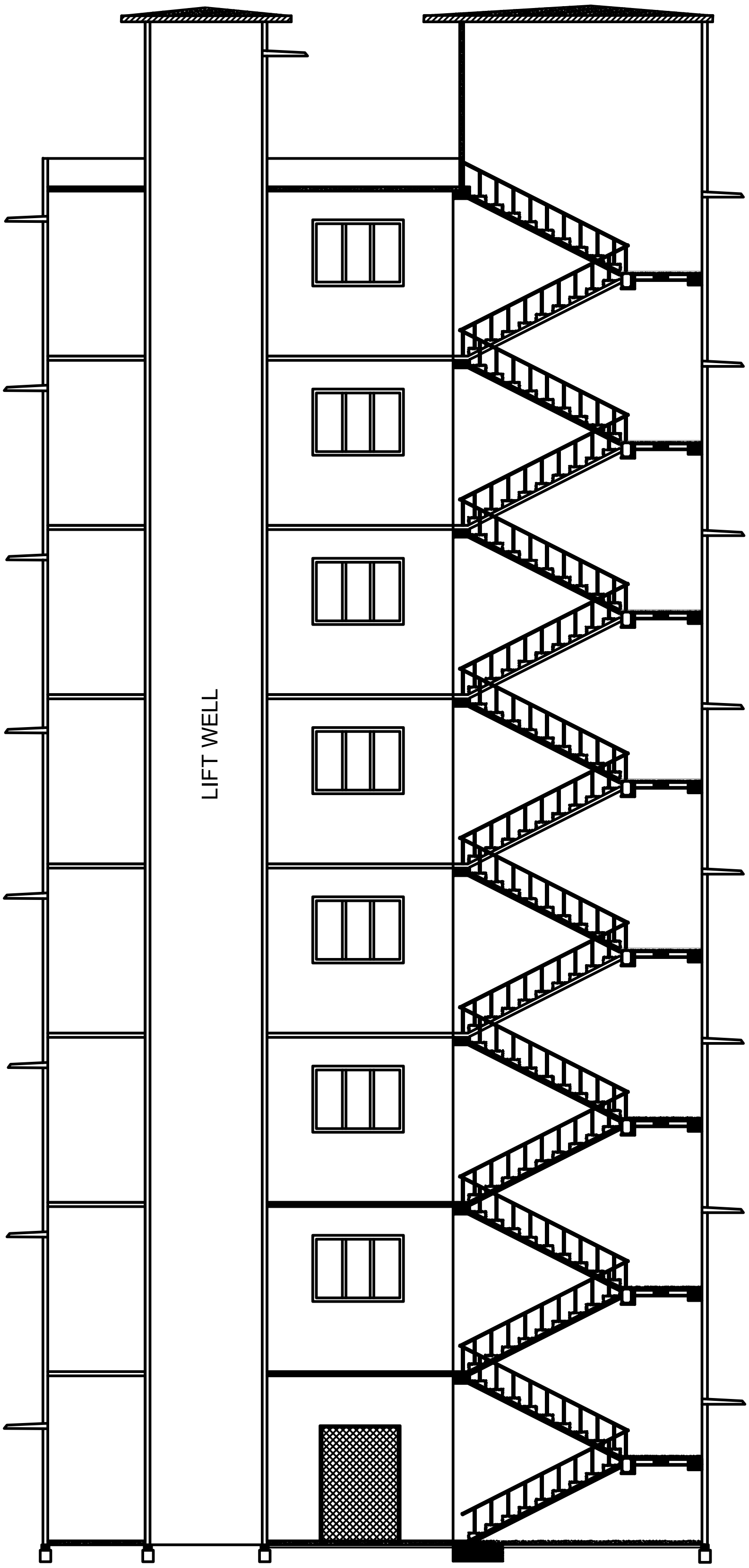


FIG. 15 CROSS-SECTION OF GFRG LIFT WELL

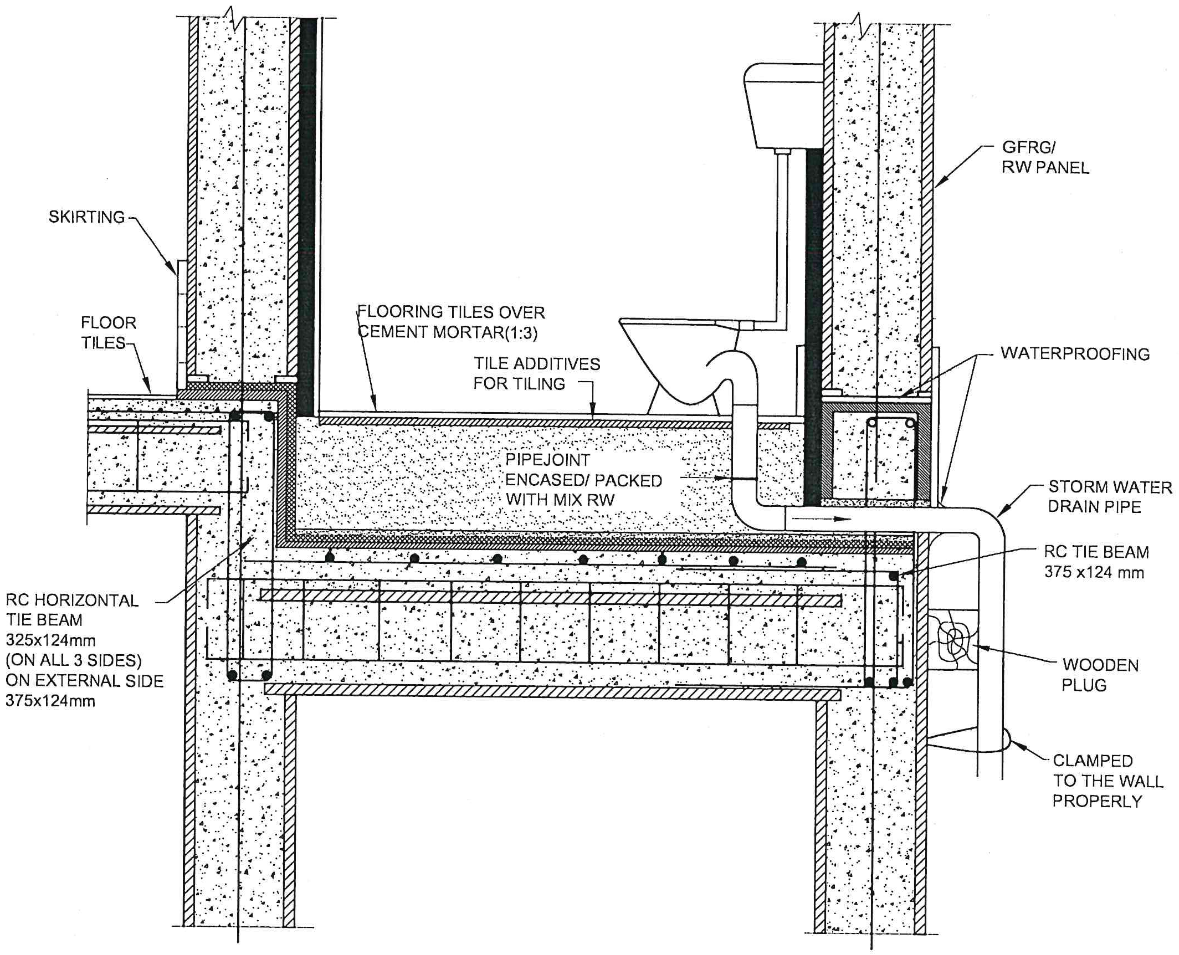

SKIRTING
FLOOR TILES
FLOORING TILES OVER CEMENT MORTAR(1:3)
TILE ADDITIVES FOR TILING
GFRG/ RW PANEL
WATERPROOFING
PIPEJOINT ENCASED/ PACKED WITH MIX RW
STORM WATER DRAIN PIPE
RC TIE BEAM 375 x124 mm
RC HORIZONTAL TIE BEAM 325x124mm (ON ALL 3 SIDES) ON EXTERNAL SIDE 375x124mm
WOODEN PLUG
CLAMPED TO THE WALL PROPERLY

FIG. 16 CROSS-SECTION OF SUNKEN FLOOR (TO BE USED IN BATH/TOILET/WET AREA)

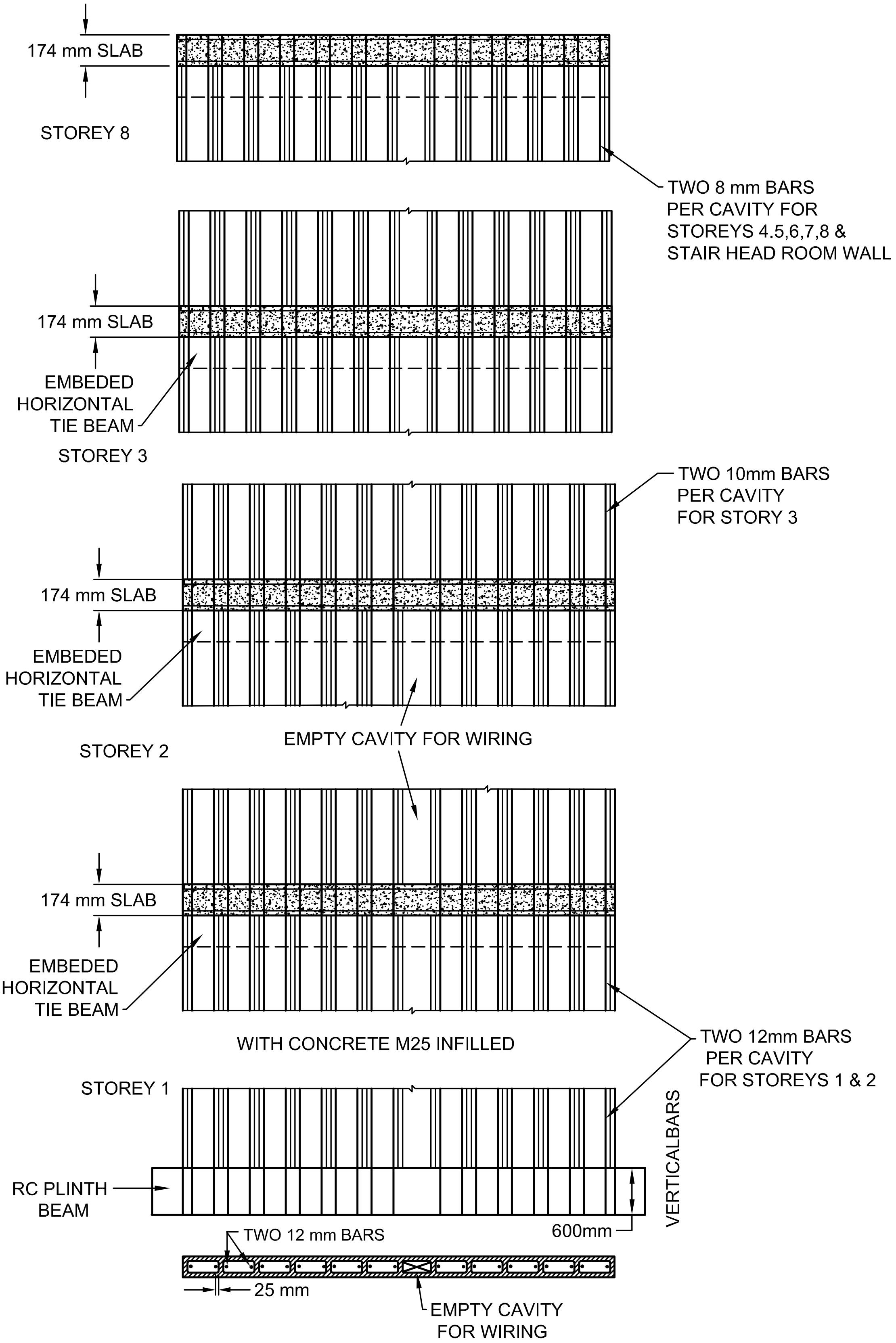

174 mm SLAB
STOREY 8
TWO 8 mm BARS PER CAVITY FOR STOREYS 4.5,6,7,8 & STAIR HEAD ROOM WALL
174 mm SLAB
EMBEDED HORIZONTAL TIE BEAM
STOREY 3
TWO 10mm BARS PER CAVITY FOR STORY 3
174 mm SLAB
EMBEDED HORIZONTAL TIE BEAM
EMPTY CAVITY FOR WIRING
STOREY 2
174 mm SLAB
EMBEDED HORIZONTAL TIE BEAM
WITH CONCRETE M25 INFILLED
TWO 12mm BARS PER CAVITY FOR STOREYS 1 & 2
STOREY 1
VERTICALBARS
RC PLINTH BEAM
600mm
TWO 12 mm BARS
25 mm
EMPTY CAVITY FOR WIRING

Fig. 17 Longitudinal Sectional View of Walls Showing Vertical Reinforcement Details

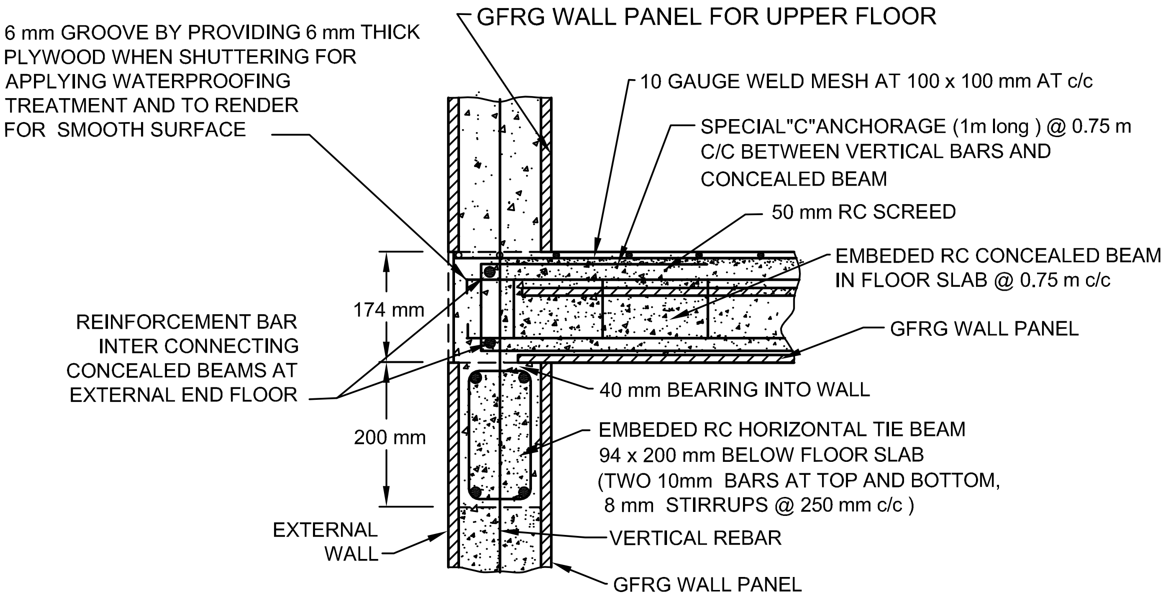

GFRG WALL PANEL FOR UPPER FLOOR
6 mm GROOVE BY PROVIDING 6 mm THICK PLYWOOD WHEN SHUTTERING FOR APPLYING WATERPROOFING TREATMENT AND TO RENDER FOR SMOOTH SURFACE
10 GAUGE WELD MESH AT 100 x 100 mm AT c/c
SPECIAL"C"ANCHORAGE (1m long) @ 0.75 m C/C BETWEEN VERTICAL BARS AND CONCEALED BEAM
50 mm RC SCREED
EMBEDED RC CONCEALED BEAM IN FLOOR SLAB @ 0.75 m c/c
174 mm
REINFORCEMENT BAR INTER CONNECTING CONCEALED BEAMS AT EXTERNAL END FLOOR
GFRG WALL PANEL
40 mm BEARING INTO WALL
200 mm
EMBEDED RC HORIZONTAL TIE BEAM 94 x 200 mm BELOW FLOOR SLAB (TWO 10mm BARS AT TOP AND BOTTOM, 8 mm STIRRUPS @ 250 mm c/c)
EXTERNAL WALL
VERTICAL REBAR
GFRG WALL PANEL

Fig. 18 Slab-Wall Connection (with Exposed Floor Slab) and Embedded Horizontal Tie Beam for Buildings More Than 4 Floors

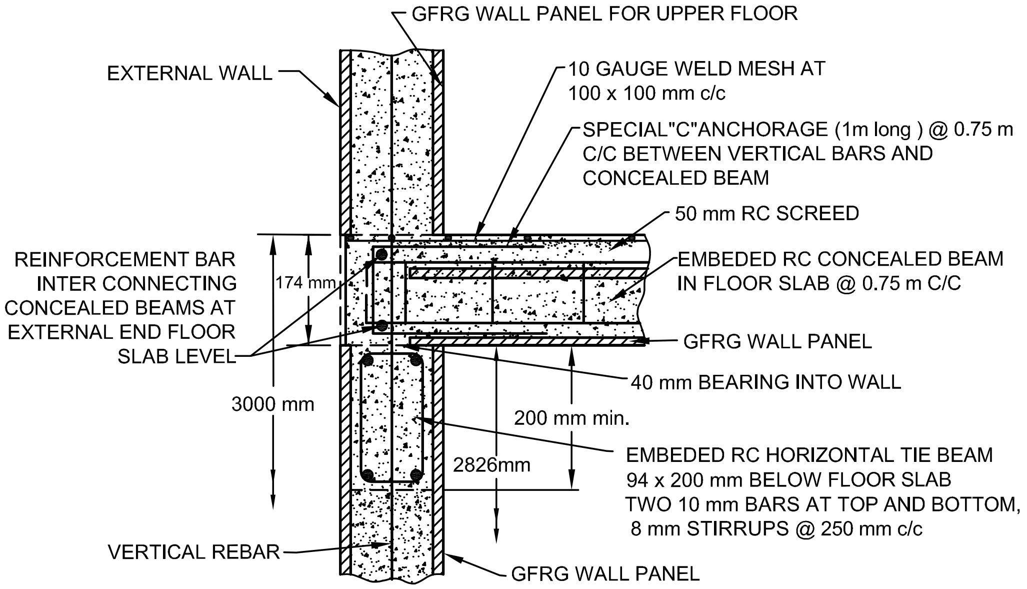
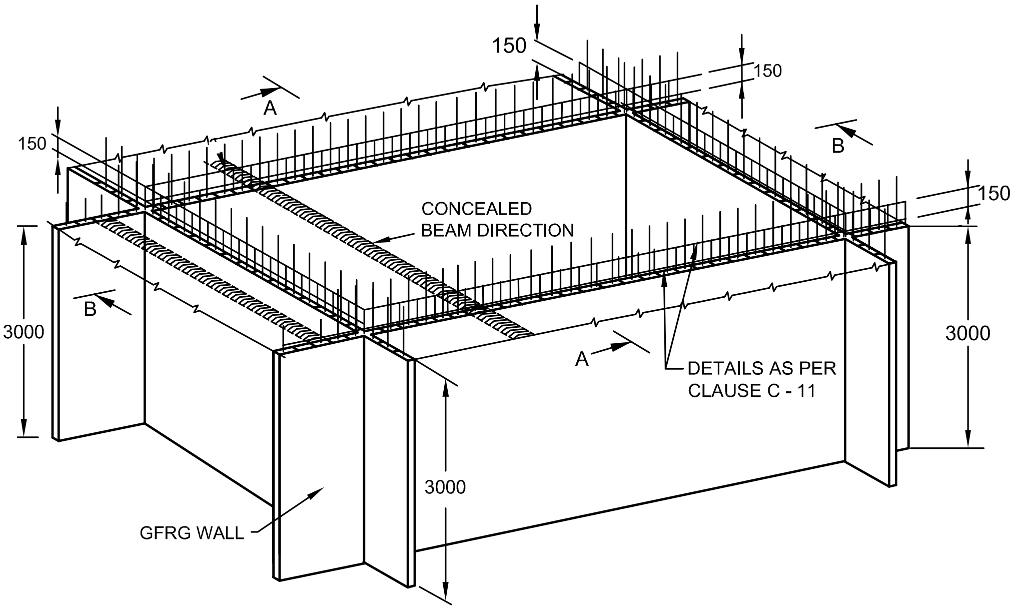

GFRG WALL PANEL FOR UPPER FLOOR
EXTERNAL WALL
10 GAUGE WELD MESH AT 100 x 100 mm c/c
SPECIAL"C"ANCHORAGE (1m long) @ 0.75 m C/C BETWEEN VERTICAL BARS AND CONCEALED BEAM
50 mm RC SCREED
REINFORCEMENT BAR INTER CONNECTING CONCEALED BEAMS AT EXTERNAL END FLOOR SLAB LEVEL
174 mm
EMBEDED RC CONCEALED BEAM IN FLOOR SLAB @ 0.75 m C/C
GFRG WALL PANEL
40 mm BEARING INTO WALL
3000 mm
200 mm min.
2826mm
EMBEDED RC HORIZONTAL TIE BEAM 94 x 200 mm BELOW FLOOR SLAB TWO 10 mm BARS AT TOP AND BOTTOM, 8 mm STIRRUPS @ 250 mm c/c
VERTICAL REBAR
GFRG WALL PANEL

Fig. 19 Slab-Wall Connection (without Exposed Floor Slab) and Embedded Horizontal Tie Beam for Buildings More Than 4 Floors



All dimensions are in mm

FIG. 20 TIE SYSTEM BETWEEN SLAB AND WALLS

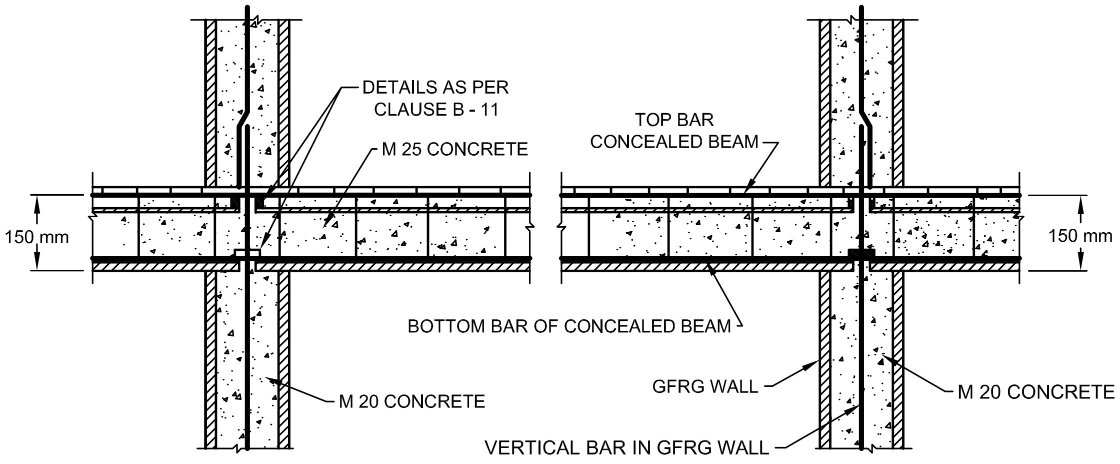


FIG. 21 SECTION A-A (*see* FIG. 20)

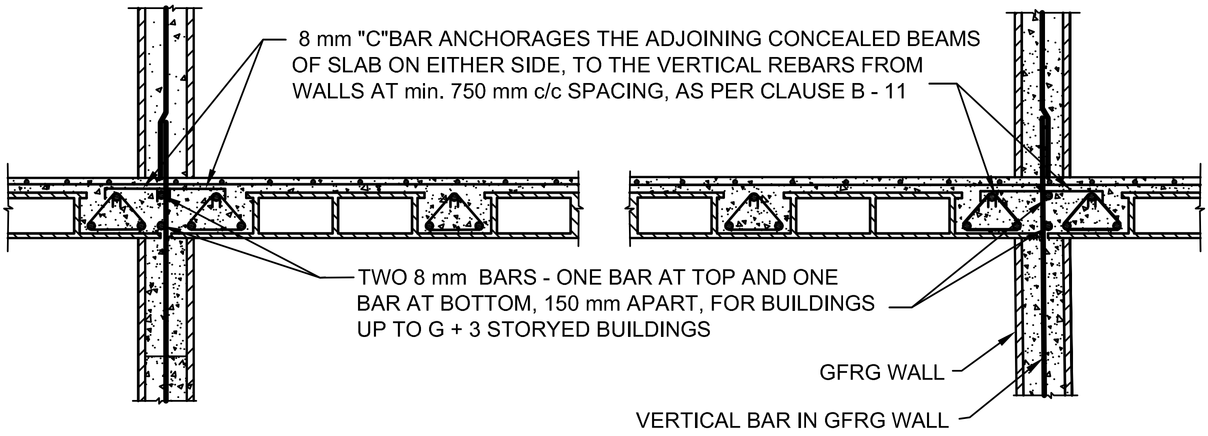

8 mm "C"BAR ANCHORAGES THE ADJOINING CONCEALED BEAMS OF SLAB ON EITHER SIDE, TO THE VERTICAL REBARS FROM WALLS AT min. 750 mm c/c SPACING, AS PER CLAUSE B - 11
TWO 8 mm BARS - ONE BAR AT TOP AND ONE BAR AT BOTTOM, 150 mm APART, FOR BUILDINGS UP TO G + 3 STORYED BUILDINGS
GFRG WALL
VERTICAL BAR IN GFRG WALL

FIG. 22 SECTION B-B (*see* FIG. 20)

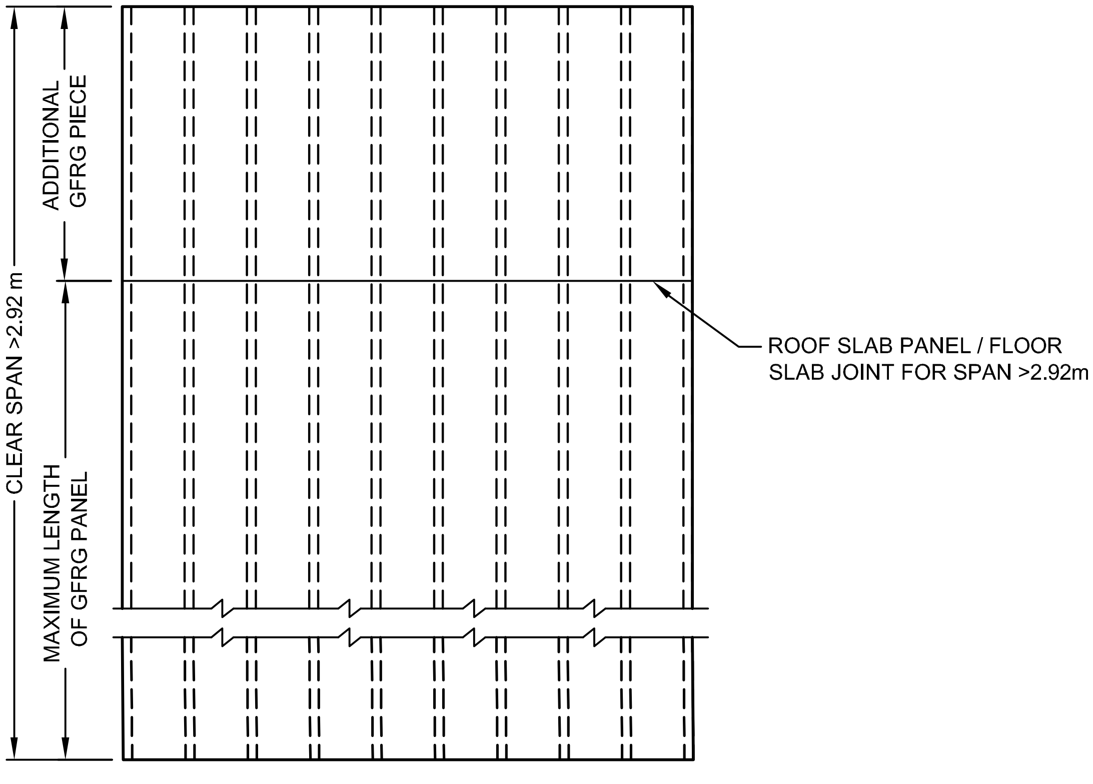

ADDITIONAL GFRG PIECE
CLEAR SPAN >2.92 m
MAXIMUM LENGTH OF GFRG PANEL
ROOF SLAB PANEL / FLOOR SLAB JOINT FOR SPAN >2.92m

FIG. 23 JOINT IN GFRG SLAB PANELS

B-12 In GFRG floor and roof slabs, when the clear span (in the direction of the ribs) exceeds 2.92 m, jointing of the GFRG panel shall be treated as shown in Figs. 23 to 27.

B-13 GFRG panels can be used as pitched roofs without concealed beams and screed concrete on top of it, for single storeyed small span buildings (typically for affordable mass housing for single separate small houses). In such cases, a tie down system shall be provided through the roof and wall panel cavities (typically using 8 mm rebars, which are tied to the starter bars in the RC plinth beam) at maximum spacing of 1.25 m and concrete infilled, for resistance against lateral loads, as illustrated in Figs. 28 to 31.

B-14 For floor/roof slab with larger spans and/or high imposed loads, or in balconies, etc, one or more intermediate supporting RC beams shall be provided (concealed inside GFRG forms), with sufficient depth protruding below the soffit of the GFRG-RC slab (typically 124 mm or 248 mm below), in a direction perpendicular to the ribs in the GFRG panel. In such cases, RC column (concealed inside GFRG forms) shall be suitably designed and provided on either end of RC beams to take care of points loads and as illustrated in Fig. 32, in accordance with IS 456.

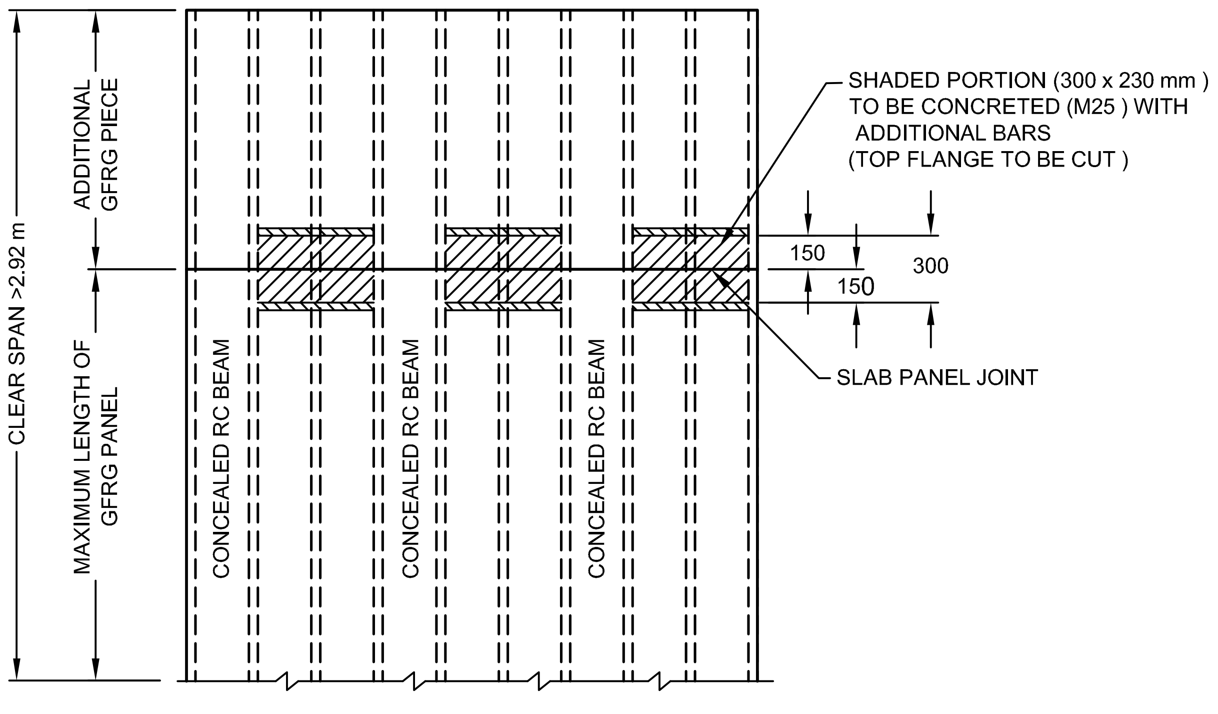

CLEAR SPAN >2.92 m
ADDITIONAL GFRG PIECE
MAXIMUM LENGTH OF GFRG PANEL
CONCEALED RC BEAM
CONCEALED RC BEAM
CONCEALED RC BEAM
SHADED PORTION (300 x 230 mm) TO BE CONCRETED (M25) WITH ADDITIONAL BARS (TOP FLANGE TO BE CUT)
150
150
300
SLAB PANEL JOINT

Fig. 24 GFRG Slab Panel Before Concreting

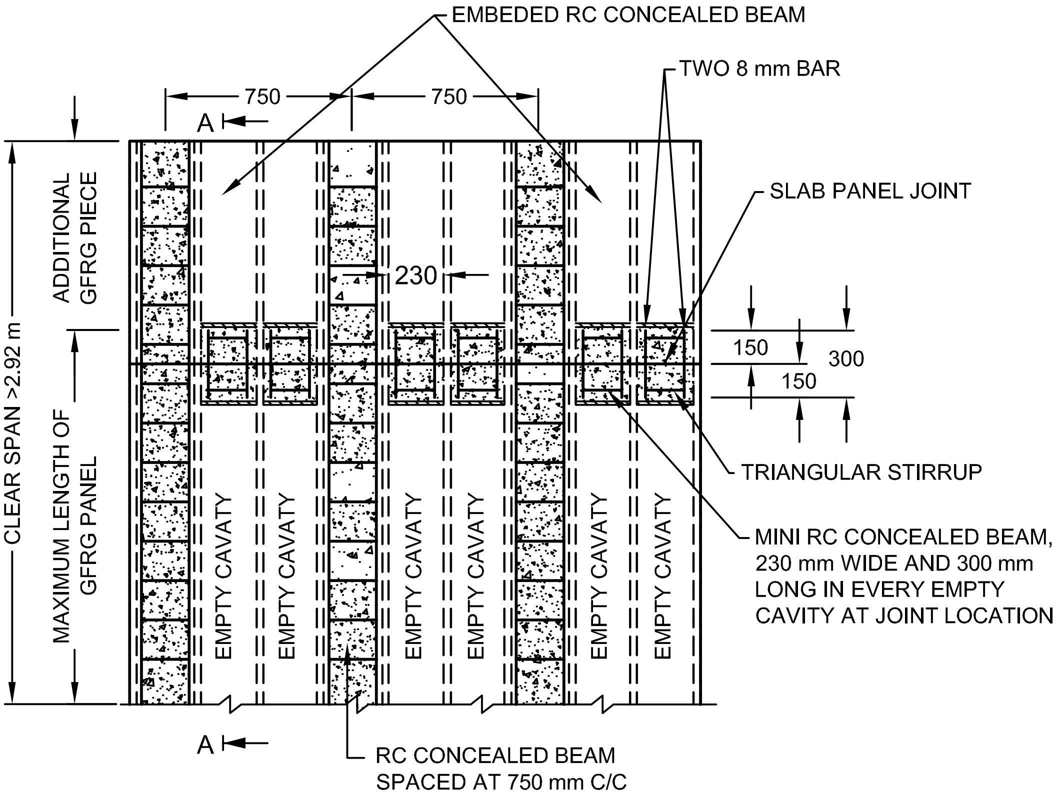

EMBEDED RC CONCEALED BEAM
TWO 8 mm BAR
750
750
A
A
SLAB PANEL JOINT
ADDITIONAL GFRG PIECE
CLEAR SPAN >2.92 m
MAXIMUM LENGTH OF GFRG PANEL
230
150
150
300
TRIANGULAR STIRRUP
MINI RC CONCEALED BEAM, 230 mm WIDE AND 300 mm LONG IN EVERY EMPTY CAVITY AT JOINT LOCATION
EMPTY CAVATY
EMPTY CAVATY
EMPTY CAVATY
EMPTY CAVATY
EMPTY CAVATY
EMPTY CAVATY
RC CONCEALED BEAM SPACED AT 750 mm C/C

FIG. 25 GFRG SLAB: PLAN OF BOTTOM LAYER REINFORCEMENT

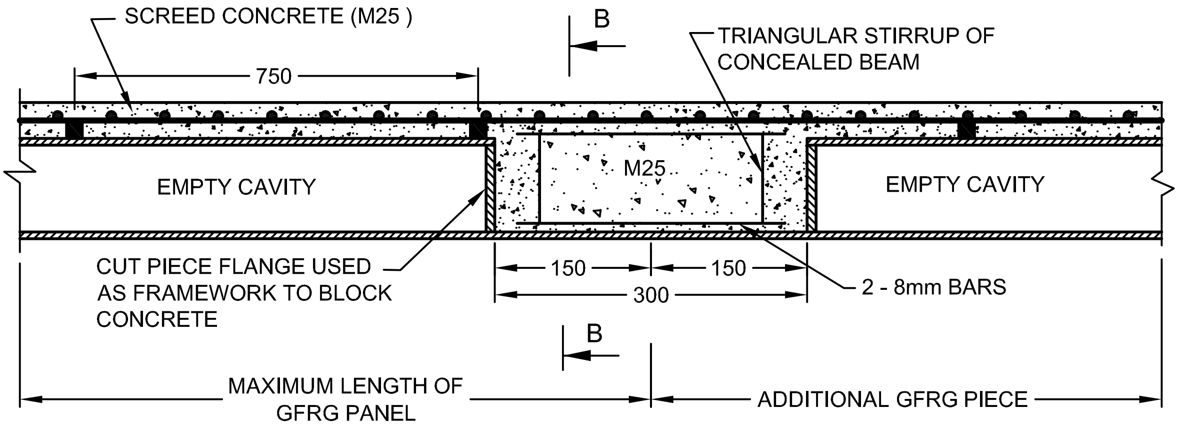

SCREED CONCRETE (M25)
750
B
TRIANGULAR STIRRUP OF CONCEALED BEAM
M25
EMPTY CAVITY
EMPTY CAVITY
CUT PIECE FLANGE USED AS FRAMEWORK TO BLOCK CONCRETE
150
150
300
2 - 8mm BARS
B
MAXIMUM LENGTH OF GFRG PANEL
ADDITIONAL GFRG PIECE

FIG. 26 CROSS-SECTION A-A (*see* FIG. 25)

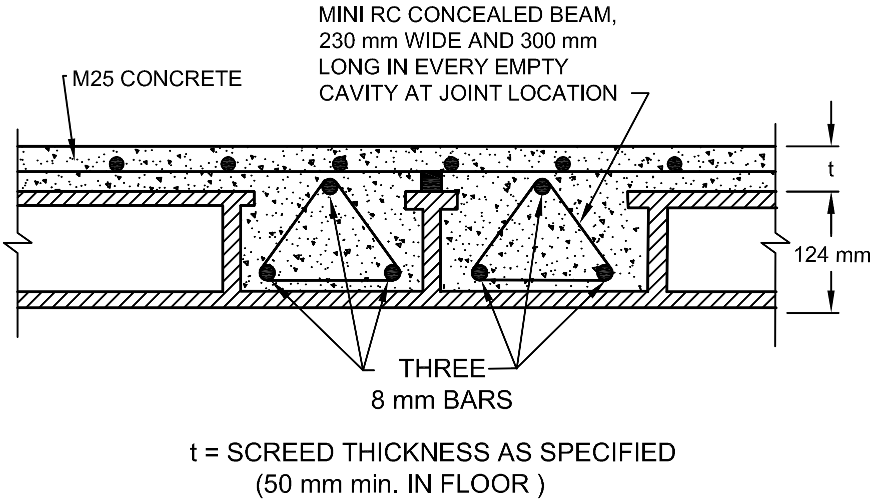

MINI RC CONCEALED BEAM, 230 mm WIDE AND 300 mm LONG IN EVERY EMPTY CAVITY AT JOINT LOCATION
M25 CONCRETE
t
124 mm
THREE 8 mm BARS
t = SCREED THICKNESS AS SPECIFIED (50 mm min. IN FLOOR)

FIG. 27 CROSS-SECTION B-B (*see* FIG. 26)

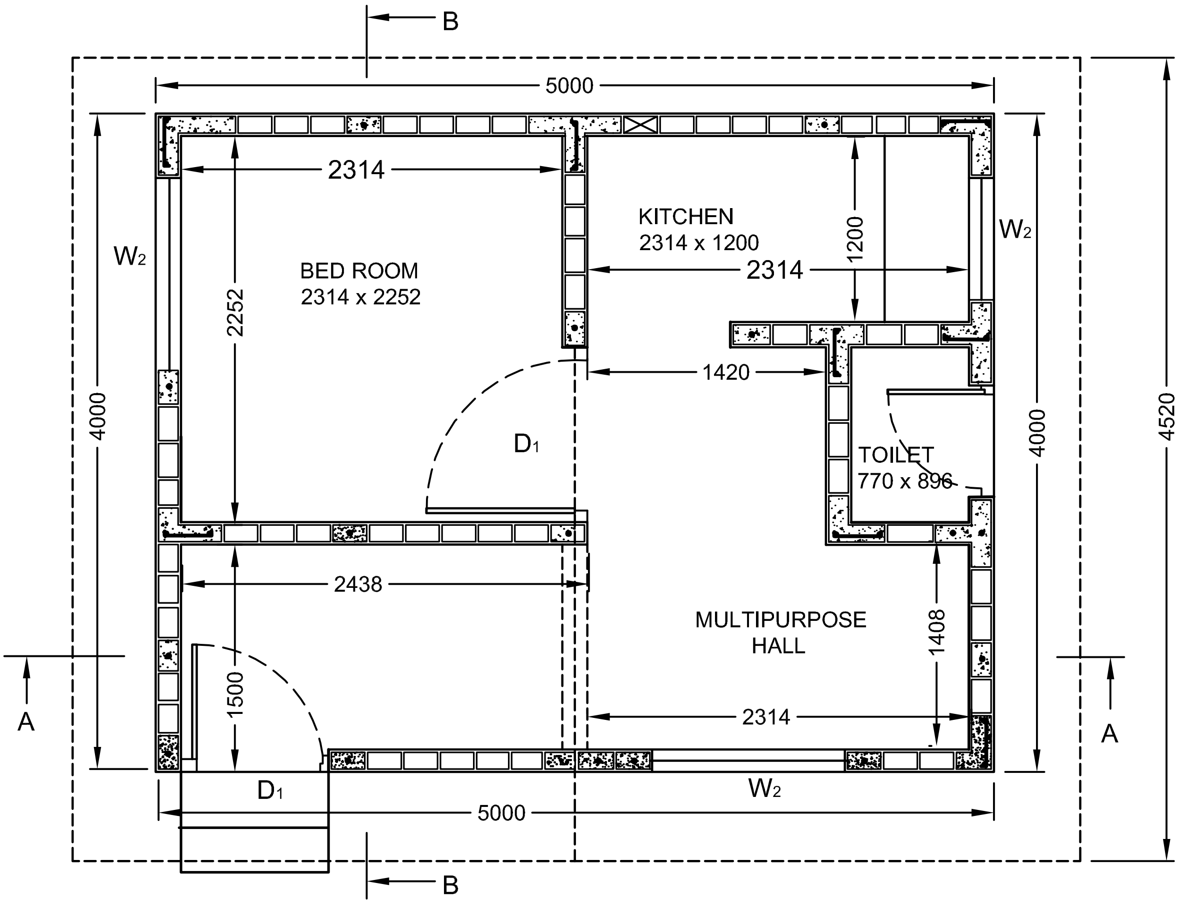


FIG. 28 TYPICAL PLAN OF GFRG BUILDING WITH PITCHED ROOF

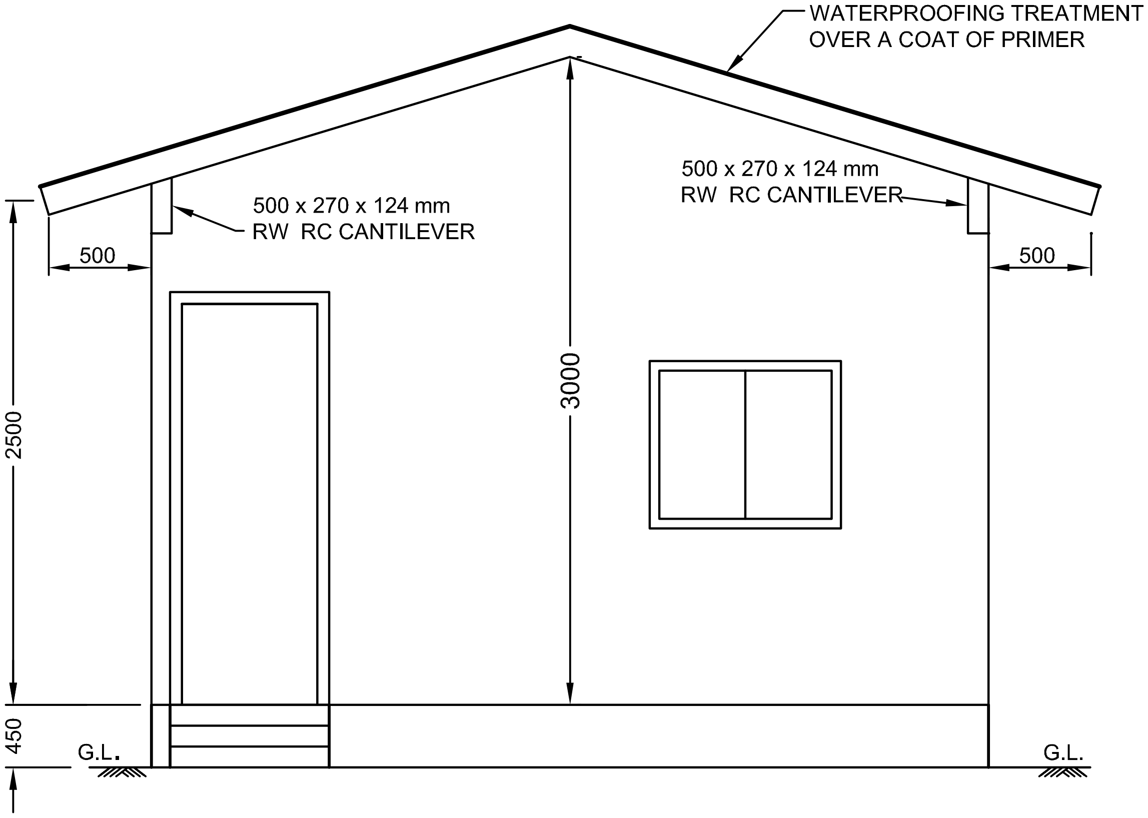


Fig. 29 Elevation of GFRG Building with Pitched Roof

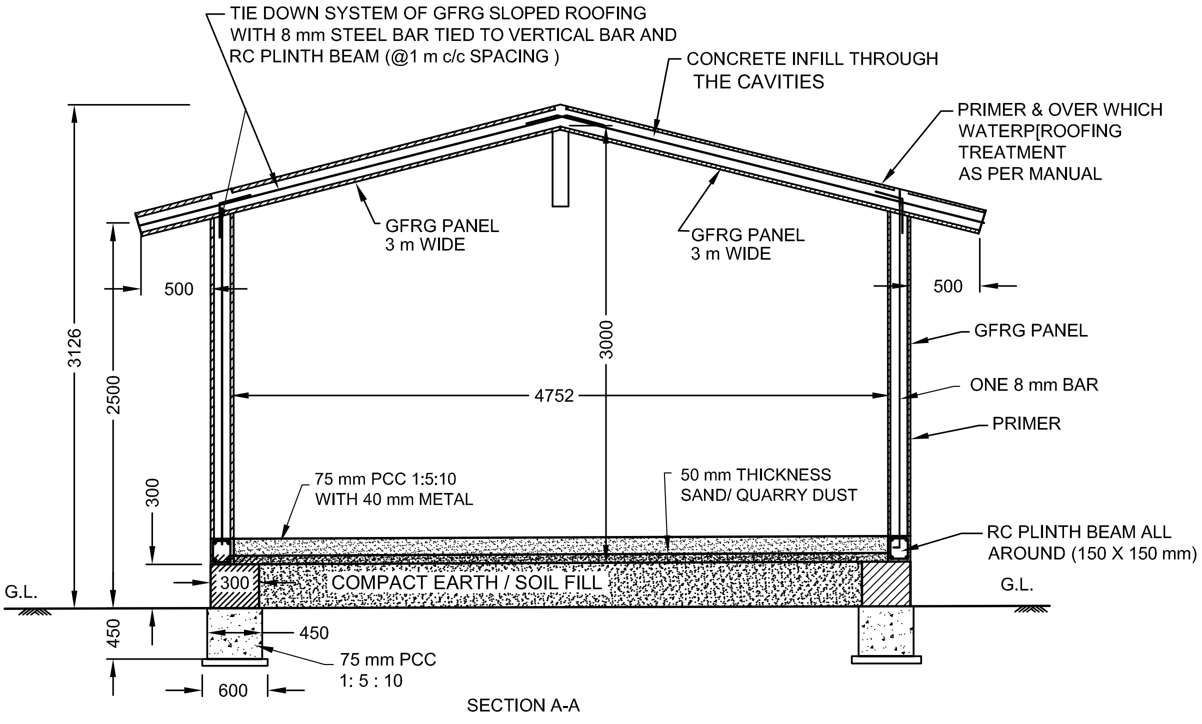


Fig. 30 Typical Sectional View Illustrates Tie Down System to Resist Lateral Loads for GFRG (*see* Fig. 28)

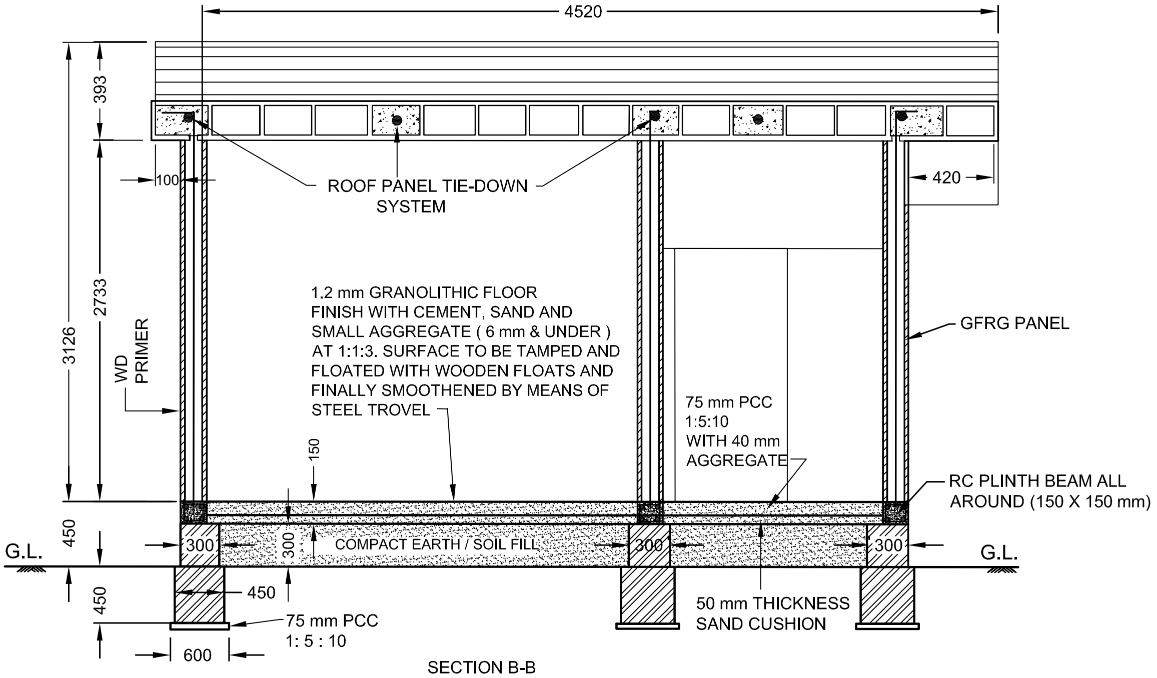

4520
393
2733
3126
100
420
ROOF PANEL TIE-DOWN SYSTEM
1.2 mm GRANOLITHIC FLOOR FINISH WITH CEMENT, SAND AND SMALL AGGREGATE (6 mm & UNDER) AT 1:1:3. SURFACE TO BE TAMPED AND FLOATED WITH WOODEN FLOATS AND FINALLY SMOOTHENED BY MEANS OF STEEL TROVEL
GFRG PANEL
WD PRIMER
75 mm PCC 1:5:10 WITH 40 mm AGGREGATE
150
RC PLINTH BEAM ALL AROUND (150 X 150 mm)
450
G.L.
300
COMPACT EARTH / SOIL FILL
300
300
300
G.L.
450
450
75 mm PCC 1: 5 : 10
50 mm THICKNESS SAND CUSHION
600
SECTION B-B

FIG. 31 TYPICAL SECTIONAL VIEW ILLUSTRATES TIE DOWN SYSTEM TO RESIST LATERAL LOADS FOR GFRG SMALL HOUSING (*see* FIG. 28)

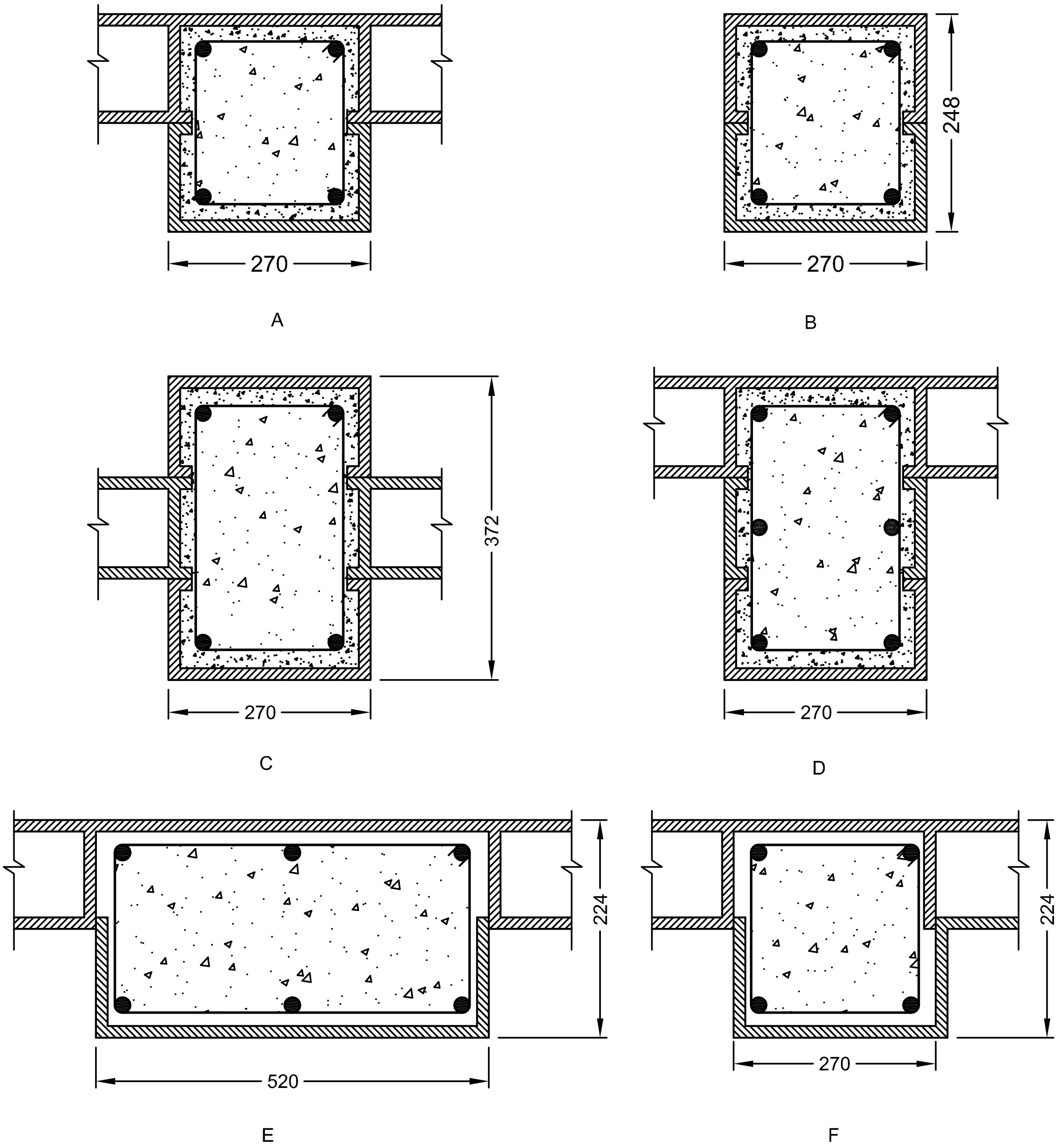


Fig. 32 Different Types of GFRG-RC Columns

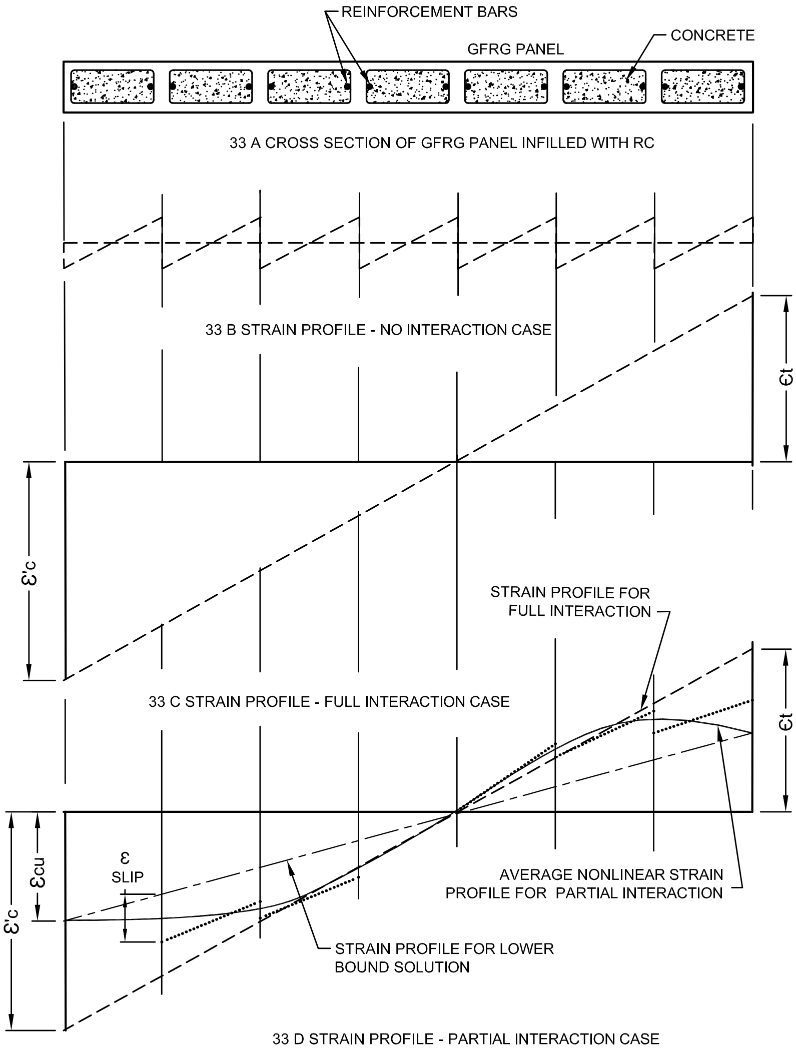
ANNEX C

(*Clauses* 11.2, 11.3 *and* B-11)

C-1 BASIC DESIGN PROCEDURE FOR GENERATING P_{UD}–M_{UD} INTERACTION DIAGRAM

C-1.1 Generation of the interaction diagram of a typical GFRG panel shall be based on a simplified procedure, which is a modified version of the lower bound solution, originally proposed by Wu (2009). Certain assumptions are made to develop the approximate interaction curve from the principles of mechanics.

C-1.2 The cross-section of a typical GFRG panel infilled with concrete and reinforcement bars in each cell is shown in Fig. 33. The behaviour of the GFRG panel infilled with concrete depends on the bond between the concrete and the GFRG panel. This is reflected in the variation of normal strain (in the vertical direction) along the length of the wall, as shown in Fig. 33. If there is no bond, there shall not be any interaction between them, resulting in small strain with multiple neutral axes, as shown in Fig. 33 B. If it is assumed that the concrete cores are fully bonded to the GFRG panel, then the "plane section remain plane" assumption is valid for the entire section and the strain profile will be a straight line with a single neutral axis, as shown in Fig. 33 C. This behaviour is similar to a reinforced concrete flexural wall. However, the limited bond between the concrete cores and the GFRG panel is difficult to quantify. The probable strain profile is likely to be as shown in Fig. 33 D. A linear 'lower bound' assumption of strain profile can be assumed with the ultimate compressive strain, ε_{cu}, as shown in Fig. 33 D. The value of ε_{cu} is limited by the out-of plane buckling strength of the panel and includes enhancement due to strain gradient for short wall lengths.


REINFORCEMENT BARS
GFRG PANEL
CONCRETE
εt
ε'c
STRAIN PROFILE FOR FULL INTERACTION
εt
ε'c
εcu
ε SLIP
AVERAGE NONLINEAR STRAIN PROFILE FOR PARTIAL INTERACTION
STRAIN PROFILE FOR LOWER BOUND SOLUTION

33 A CROSS SECTION OF GFRG PANEL INFILLED WITH RC

33 B STRAIN PROFILE - NO INTERACTION CASE

33 C STRAIN PROFILE - FULL INTERACTION CASE

33 D STRAIN PROFILE - PARTIAL INTERACTION CASE

Fig. 33 Strain Profiles for Nil, Full and Partial Interaction Between GFRG Panel and Concrete

C-1.3 Distribution of Strain at Ultimate Limit State

Fig. 34 depicts how the value ε_{cu} is to be computed depending on the location of the neutral axis x_u (from the extreme compression location), which in turn depends on the eccentricity of loading, $e = M_{ud}/P_{ud}$.

Case 1 : Pure compression ($x_u \rightarrow \infty$)

Under pure compression, (e → 0, $x_u \rightarrow \infty$), ε_{cu} is limited to : $\varepsilon_{c0} = \dfrac{p}{E}$

where p is the compressive stress of the wall at the axial buckling load (to be taken as 1360/1.5 = 907 kN/m, (*see* Table 2) and E is the effective Young's modulus of the composite wall given by :

$$E = \frac{E_C A_C + E_G A_G}{A_C + A_G}$$

where A_C and A_G are the areas of the concrete and the GFRG panel, respectively; and $E_c = 5000\sqrt{f_{ck}}$ (in MPa) and E_G are the values of elastic modulus of concrete and the GFRG panel (*see* Table 1) respectively. Typical values of E using M 20 and M 25 grades of concrete are 17 860 MPa and 19 500 MPa respectively.

Case 2 : Pure bending ($x_u = x_{u,\min}$)

For the extreme case of pure in-plane bending ($e \rightarrow \infty, x_u = x_{u,\min}$), an enhancement over ε_{c0} is proposed as follows:

$$\varepsilon_{cu} = \varepsilon_{c0}\left(1+\alpha\right)$$

where

$$\alpha = \begin{cases} 0.8\left(2-D\right) & : \text{ for } 1 \le D \le 2.0\,\text{m} \\ 0 & : \text{ for } D > 2.0\text{ m} \end{cases}$$

Case 3 : Neutral axis at edge of section ($x_u = D$)

For the case, ($x_u = D$) , the value of ε_{cu} shall be taken as:

$$\varepsilon_{cu} = \varepsilon_{c0}\left(1+0.5\alpha\right)$$

Case 4 : Neutral axis outside section ($x_u > D$)

When the neutral axis lies outside the section ($x_u > D$), the maximum compressive strain $\varepsilon_{cu} = \varepsilon_{cu1}$ can be calculated by linear interpolation. The point of intersection of the two limiting strain profiles, corresponding to $x_u = D$ and $x_u = \infty$, acts like a 'pivot' point through which all strain profiles pass when $x_u > D$, as shown in Fig. 34. The values of the maximum compressive strain at edge 1, ε_{cu1}, and strain at edge 2, ε_{cu2} are accordingly given by:

$$\varepsilon_{cu1} = \frac{\varepsilon_{c0}}{(1-x_p/x_u)} \quad \text{for } x_u > D$$

$$\varepsilon_{cu2} = \frac{\varepsilon_{cu1}\,(x_u - D)}{x_u} \quad \text{for } x_u > D$$

where

$$x_p = D\left(1-\frac{1}{1+0.5\alpha}\right)$$

Case 5 : Neutral axis inside section ($x_u < D$)

When the neutral axis lies inside the section ($x_u < D$), linear interpolation shall be done to obtain the value of ε_{cu} :

$$\varepsilon_{cu} = \varepsilon_{c0}\left[1+0.5\alpha\left(1+\frac{D-x_u}{D-x_{u,\min}}\right)\right] \quad \text{for } x_{u,\min} < x_u < D$$

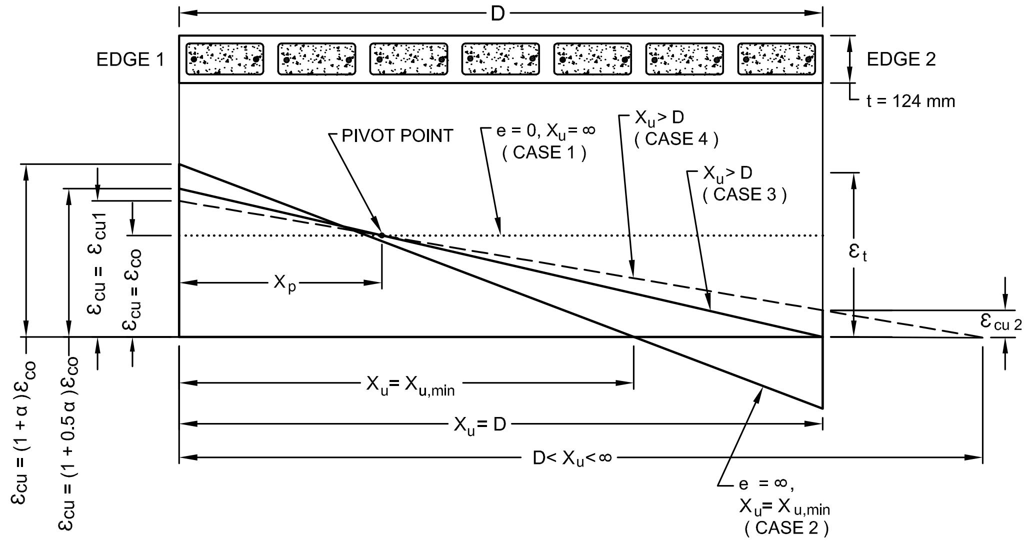


FIG. 34 RECOMMENDED STRAIN PROFILE FOR DESIGN

C-2 GENERATION OF DESIGN INTERACTION CURVE

C-2.1 A typical interaction diagram, with critical points marked, is shown in Fig. 35. The design strength of a wall panel subject to in-plane moment, M_{ud} and axial load, P_{ud} with eccentricity, e = M_{ud}/P_{ud}, comprises values of M_{ud} (corresponding to $0 < e < \infty$), all of which can be described by a single curve, termed as design interaction curve. The analysis for design strength basically entails two conditions: strain compatibility and force equilibrium.

Point A **:** Pure compression: $e = 0, x_u \rightarrow \infty$

$P_{ud} = pDt$ kN/m; $M_{ud} = 0$ kNm/m

where D is in m.

Between points A and B **:** $x_u > D$

$$P_{ud} = \left(\frac{\varepsilon_{cu1} + \varepsilon_{cu2}}{2}\right) EDt$$

$$M_{ud} = P_{ud}\left(\frac{D}{2} - \bar{x}_1\right)$$

where $\bar{x}_1$ is the centroid of the compressive force from the edge 1, given by

where $\bar{x}_1 = \dfrac{D}{3}\dfrac{(2\varepsilon_{cu2} + \varepsilon_{cu1})}{(\varepsilon_{cu1} + \varepsilon_{cu2})}$

Between points B and C **:** $x_{ub} \leq x_u < D$

where x_{ub} is the neutral axis depth corresponding to balancing point when the strain in the steel, ε_t reaches its yield strain, ε_y. The corresponding strain and stress variation across the panel width is shown in Fig. 36.

The resultant compressive force, F_c the resultant tensile force, F_t the values of P_{ud} and M_{ud} can be calculated from the Fig. 36, as follows.

$$F_c = \frac{(1+\alpha)\, pt\, x_u}{2}$$

$$F_t = \varepsilon_t E_s a_s \frac{(D - x_u)}{2}$$

$$P_{ud} = F_c - F_t$$

$$M_{ud} = F_c\left(\frac{D}{2} - \frac{x_u}{3}\right) + F_t\left(\frac{D}{2} - \frac{D - x_u}{3}\right)$$

where, a_s is area of reinforcement per unit length.

Between points C and D **:** $x_{u,min} \leq x_u < x_{ub}$

The corresponding strain and stress variation across the panel width is shown in Fig. 37.

The resultant compressive force, F_c the resultant tensile force, F_t and the values of P_{uc} and M_{uc} can be calculated from Fig. 37, as follows:

$$F_c = \frac{(1+\alpha)\, p\, t\, x_u}{2}$$

$$F_{t1} = 0.5 f_y\, a_s\, x_1$$

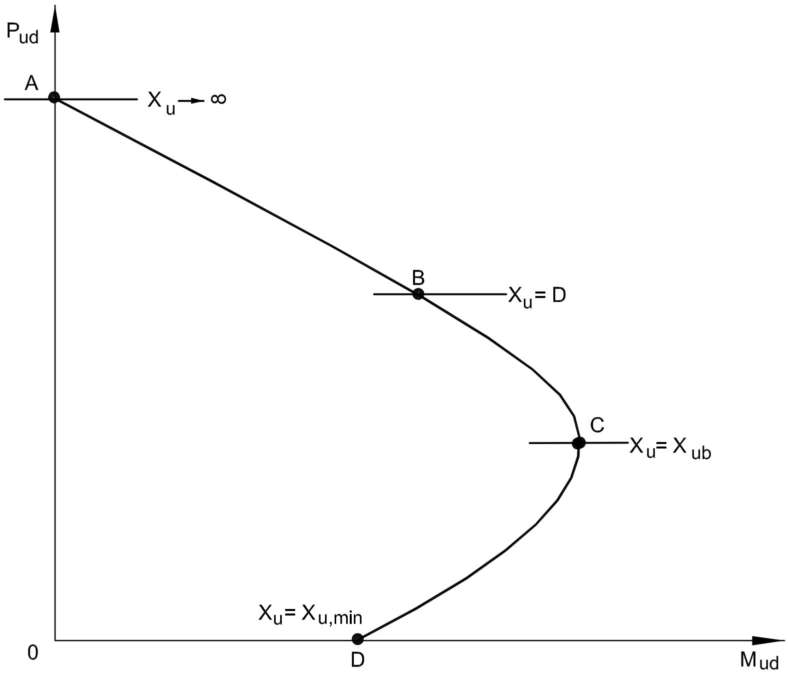


Fig. 35 Typical P_U – M_U Interaction Curve

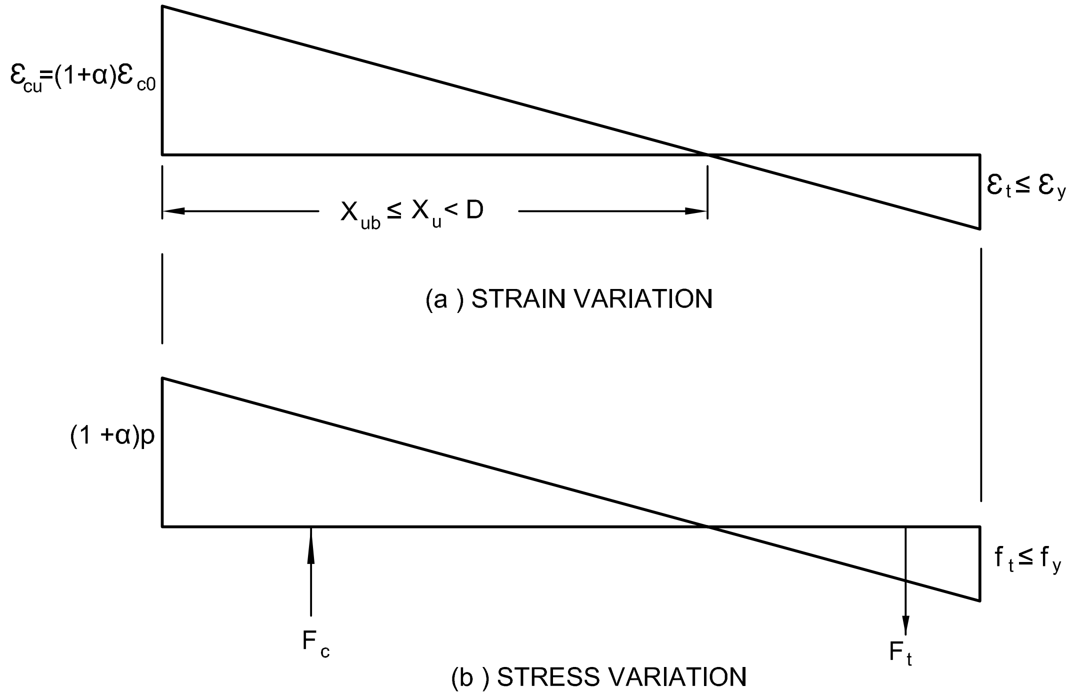


Fig. 36 Stress and Strain Variation Across Cross-Section

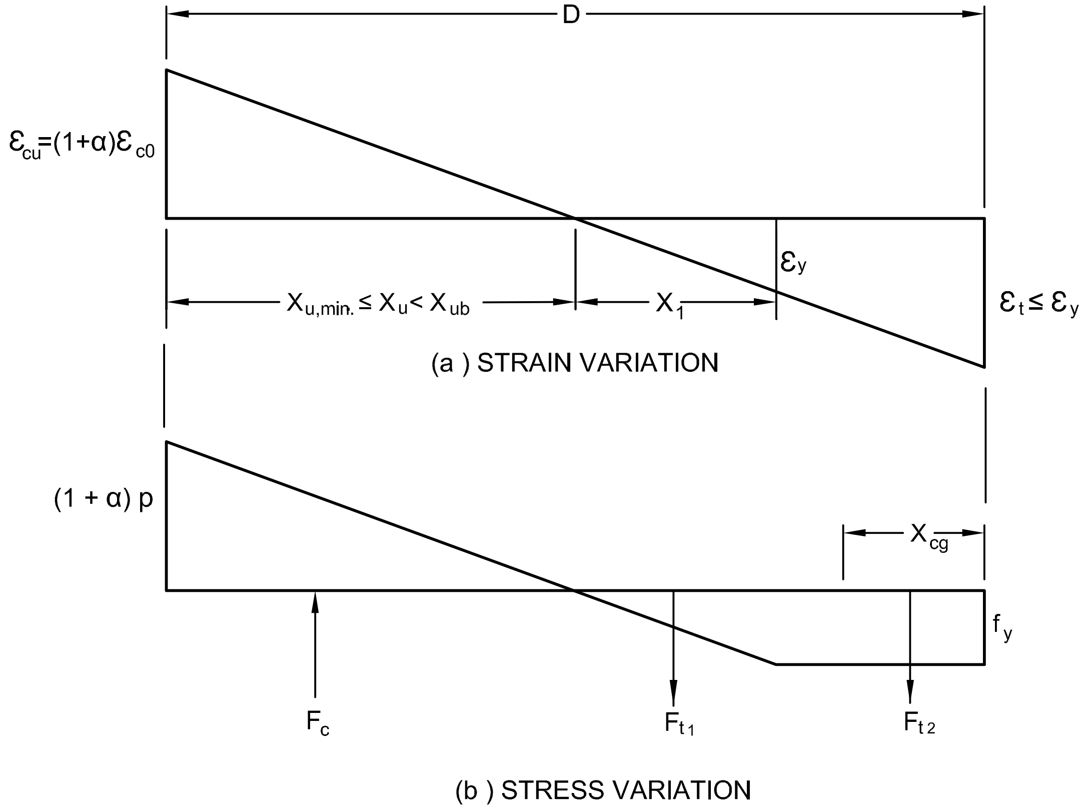

D
$\varepsilon_{cu}=(1+\alpha)\varepsilon_{c0}$
ε_y
$X_{u,min.} \leq X_u < X_{ub}$
X_1
$\varepsilon_t \leq \varepsilon_y$
(a) STRAIN VARIATION
(1 + α) p
X_{cg}
f_y
F_c
F_{t1}
F_{t2}
(b) STRESS VARIATION

Fig. 37 Stress and Strain Variation Across Cross Section after Steel Yields

where

$$x_1 = \frac{\varepsilon_y x_u}{\varepsilon_{cu}}$$

$$F_{t2} = f_y a_s \left(D - x_u - x_1\right)$$

$$F_t = F_{t1} + F_{t2}$$

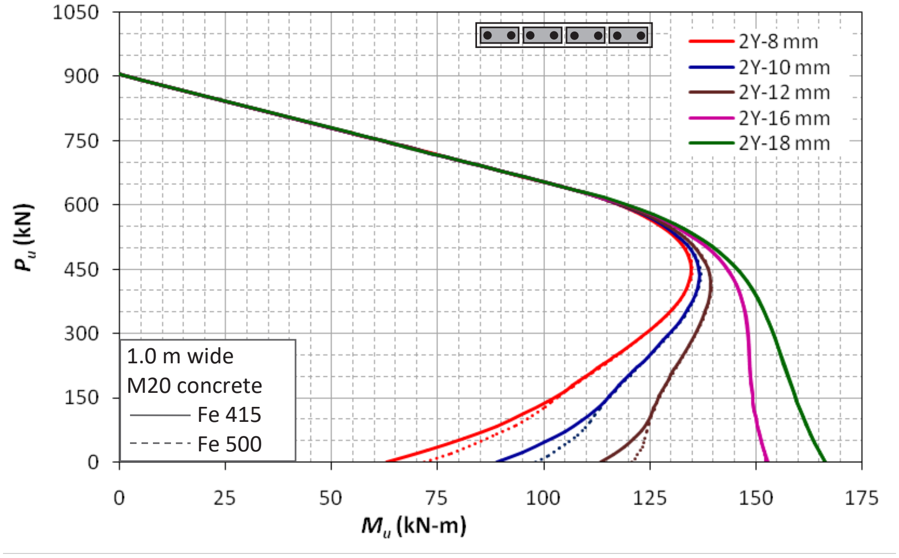
$$P_{ud} = F_c - F_t$$

$$M_{ud} = F_c\left(\frac{D}{2} - \frac{x_u}{3}\right) + F_t\left(\frac{D}{2} - x_{cg}\right)$$

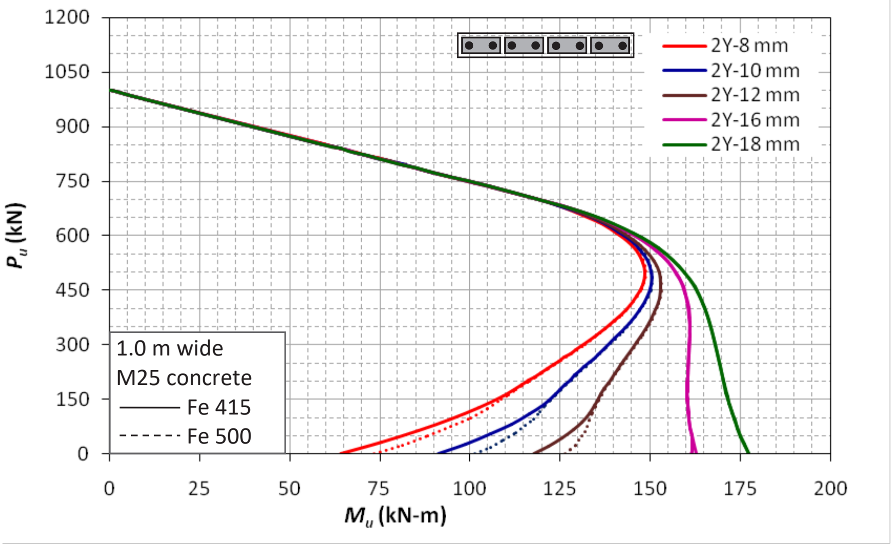
Where x_{cg} is the distance from the right side of the panel, as shown in Fig. 37, through which the resultant of forces F_{t1} and F_{t2} acts.

C-3 DESIGN P_{ud}–M_{ud} INTERACTION DIAGRAMS

Design interaction curves of GFRG panels partially/fully infilled with reinforced concrete (with one or two reinforcement bars in each cavity) for 1.0 m to 3.5 m with intervals of 0.25 m, are shown in Figs. 38 to 57

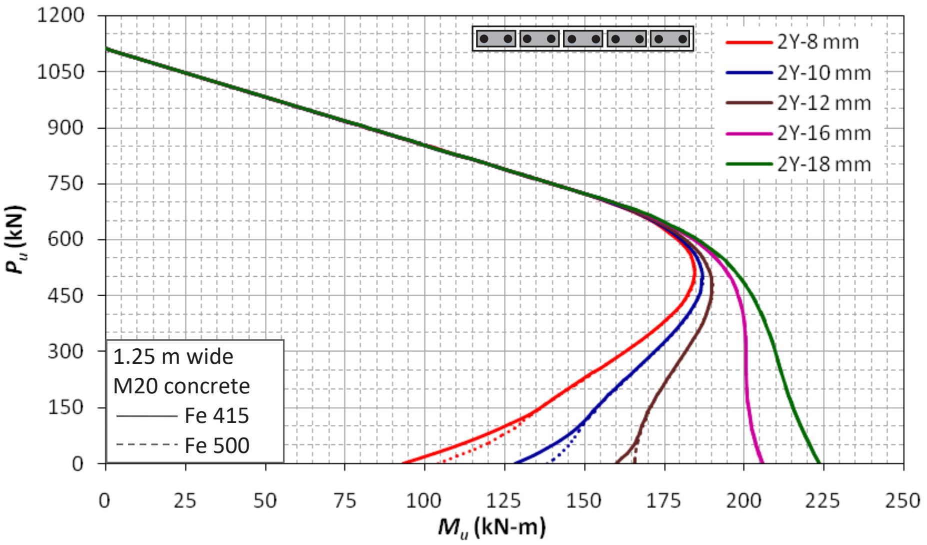


(a) Using M 20 concrete

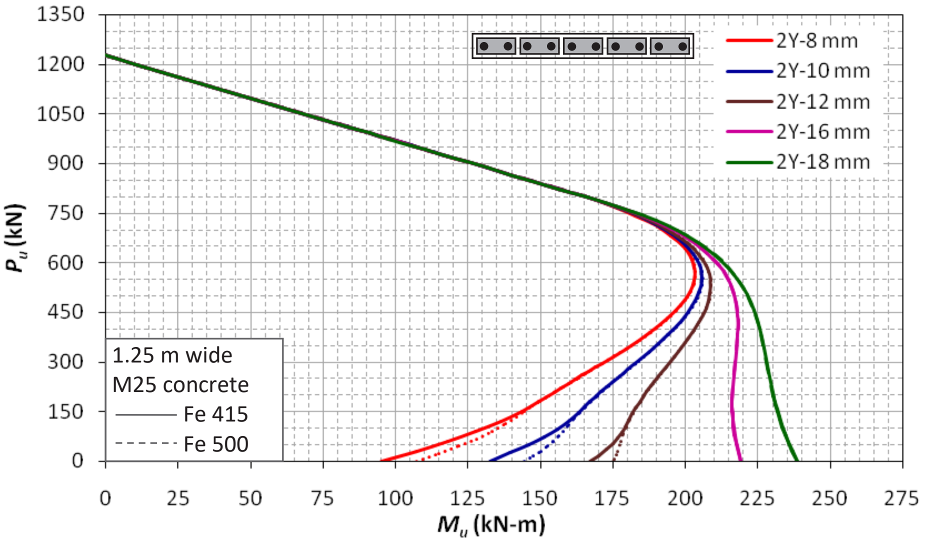


(b) Using M 25 concrete

FIG. 38 DESIGN P_U–M_U PLOTS FOR 1.0 m WIDE GFRG PANEL WITH TWO REINFORCING BARS IN EACH CAVITY

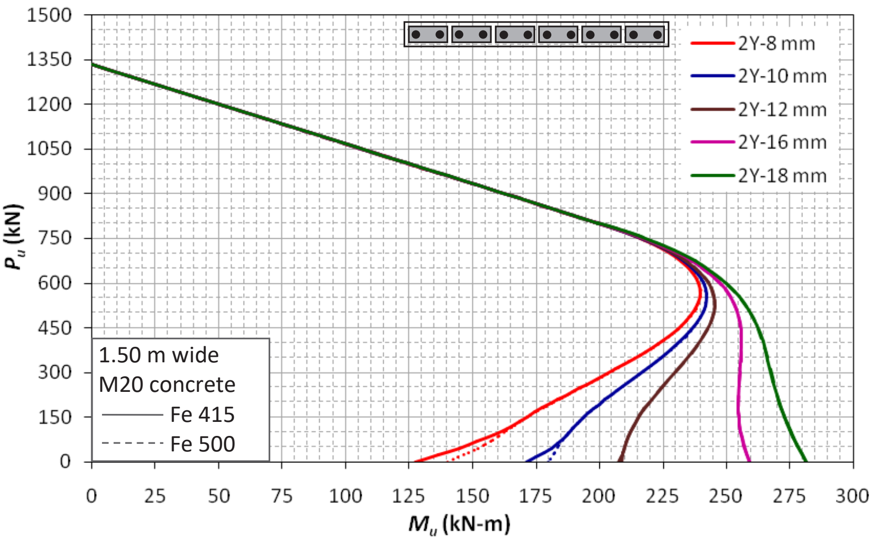


(a) Using M 20 concrete

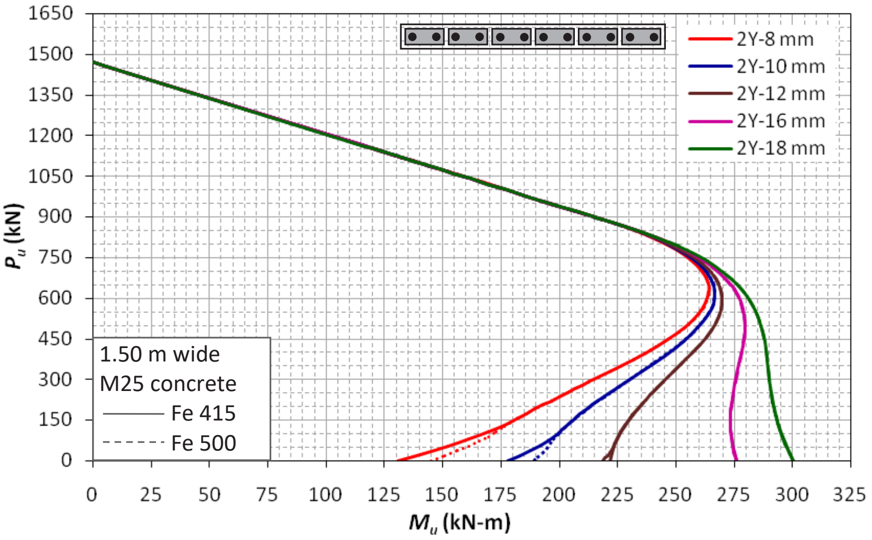


(b) Using M 25 concrete

Fig. 39 Design P_u–M_u Plots for 1.25 m Wide Gfrg Panel with Two Reinforcing Bars in Each Cavity

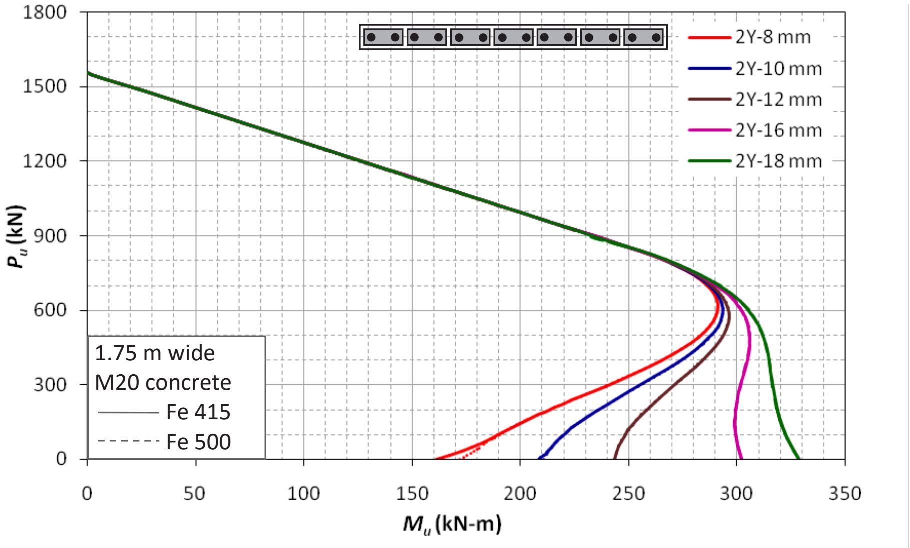


(a) Using M 20 concrete

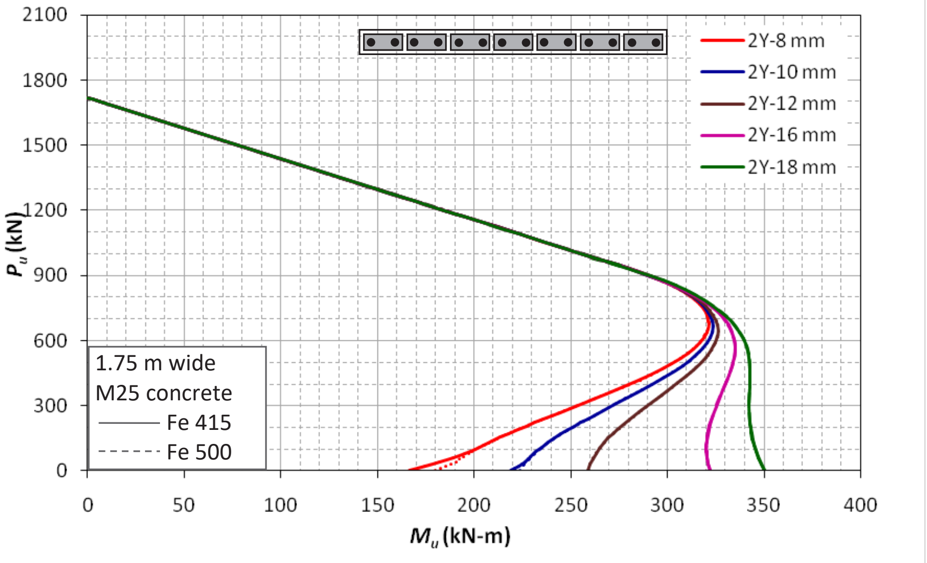


(b) Using M 25 concrete

FIG. 40 DESIGN P_U–M_U PLOTS FOR 1.50 M WIDE GFRG PANEL WITH TWO REINFORCING BARS IN EACH CAVITY

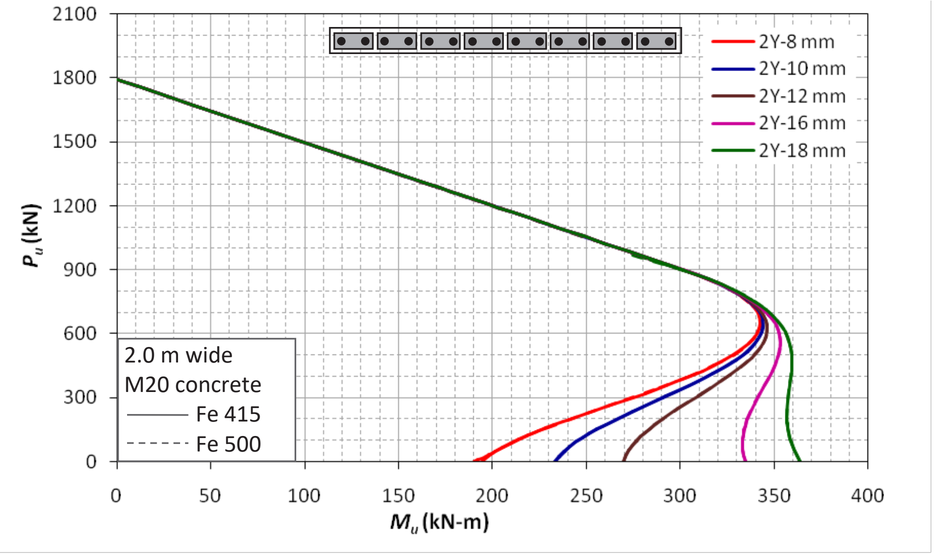


(a) Using M 20 concrete

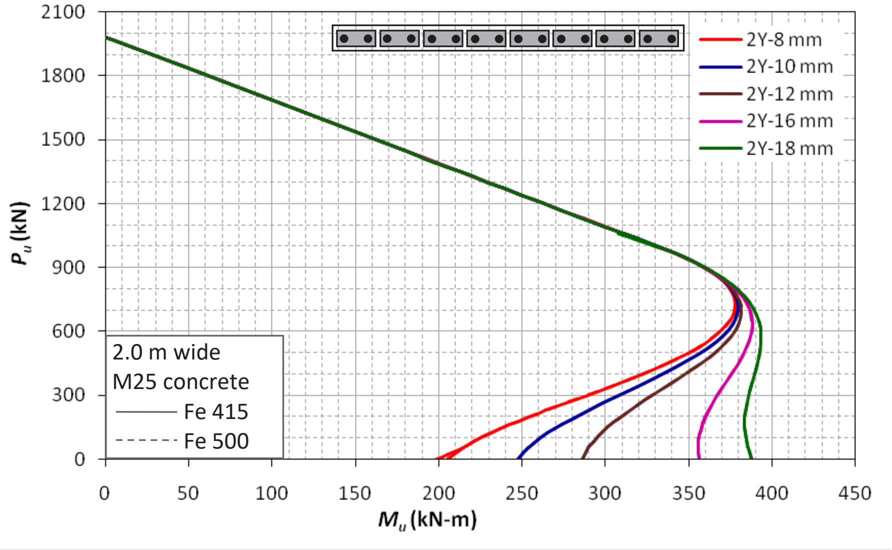


(b) Using M 25 Concrete

Fig. 41 Design P_u–M_u Plots for 1.75 m Wide GFRG Panel with Two Reinforcing Bars in Each Cavity

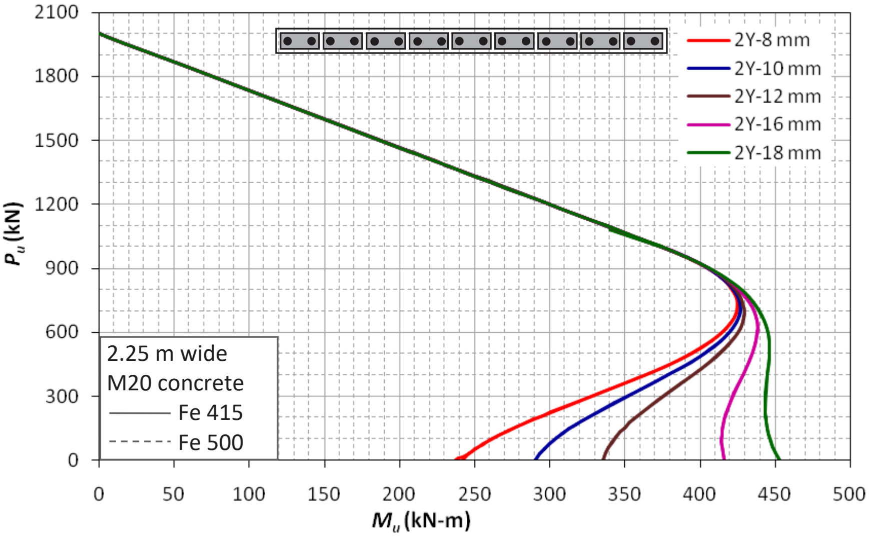


(a) Using M 20 Concrete

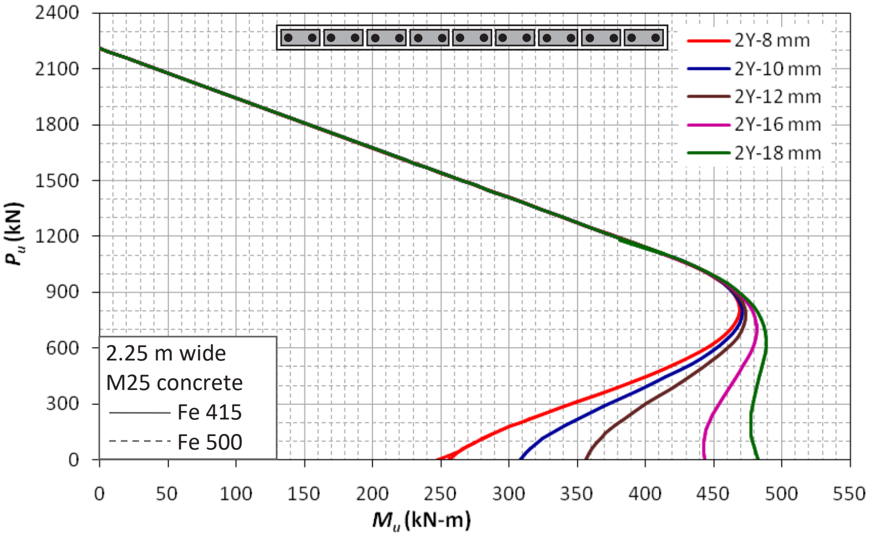


(b) Using M 25 Concrete

FIG. 42 DESIGN P_u–M_u PLOTS FOR 2.0 m WIDE GFRG PANEL WITH TWO REINFORCING BARS IN EACH CAVITY

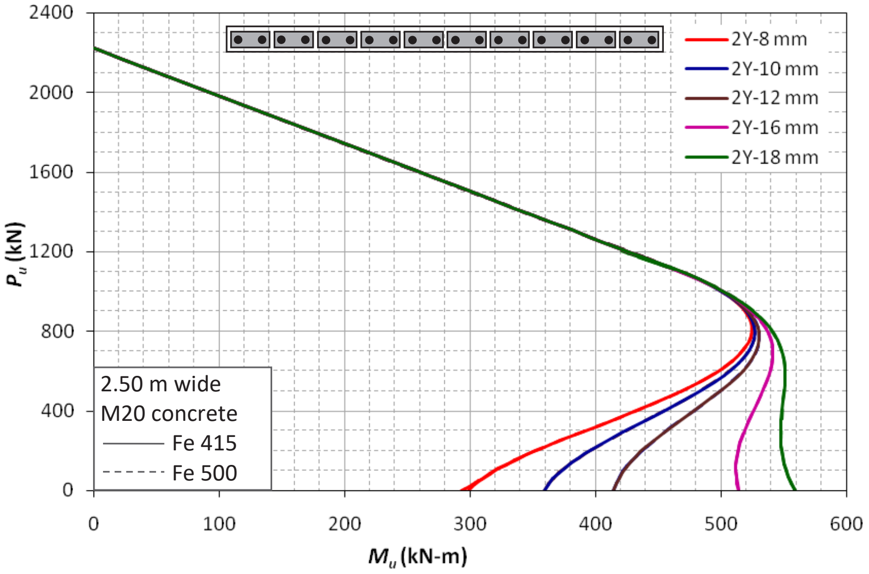


(a) Using M 20 Concrete

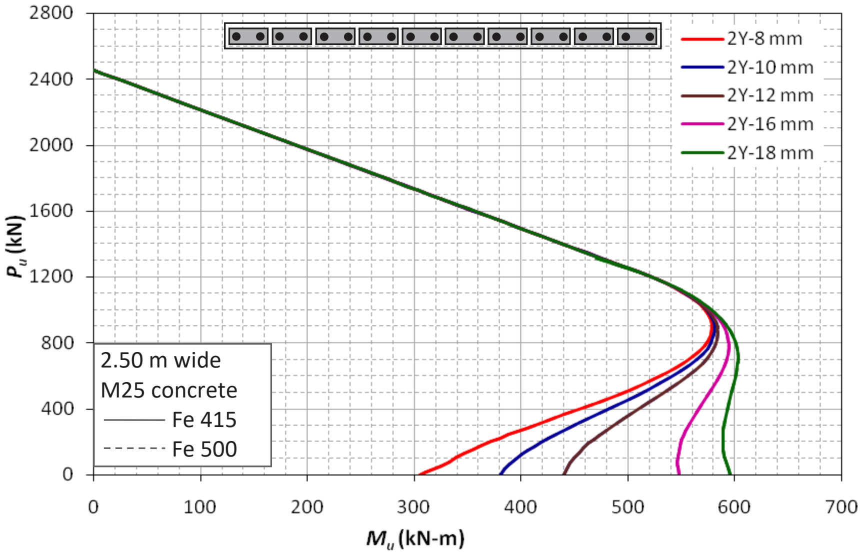


(b) Using M 25 Concrete

FIG. 43 DESIGN P_u–M_u PLOTS FOR 2.25 m WIDE GFRG PANEL WITH TWO REINFORCING BARS IN EACH CAVITY

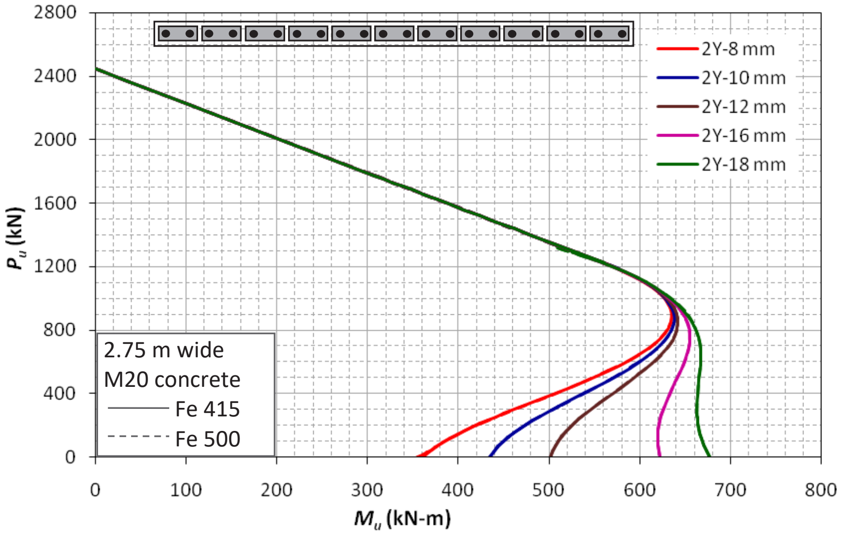


(a) Using M 20 Concrete

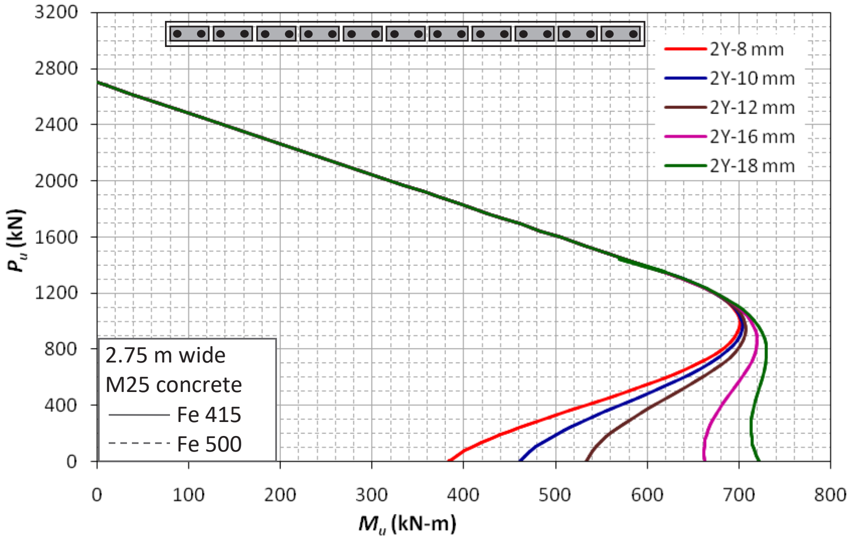


(b) Using M 25 Concrete

Fig. 44 Design P_U–M_U Plots for 2.50 m Wide GFRG Panel with Two Reinforcing Bars in Each Cavity

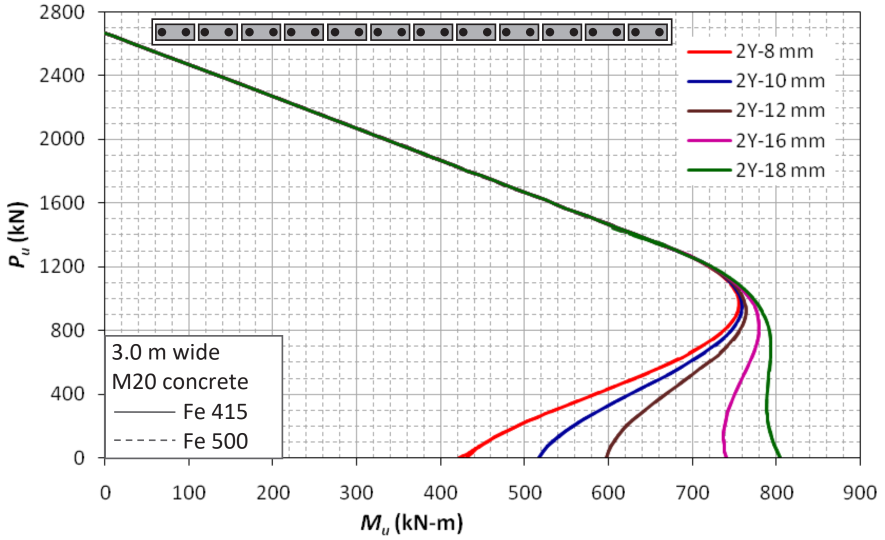


(a) Using M 20 Concrete

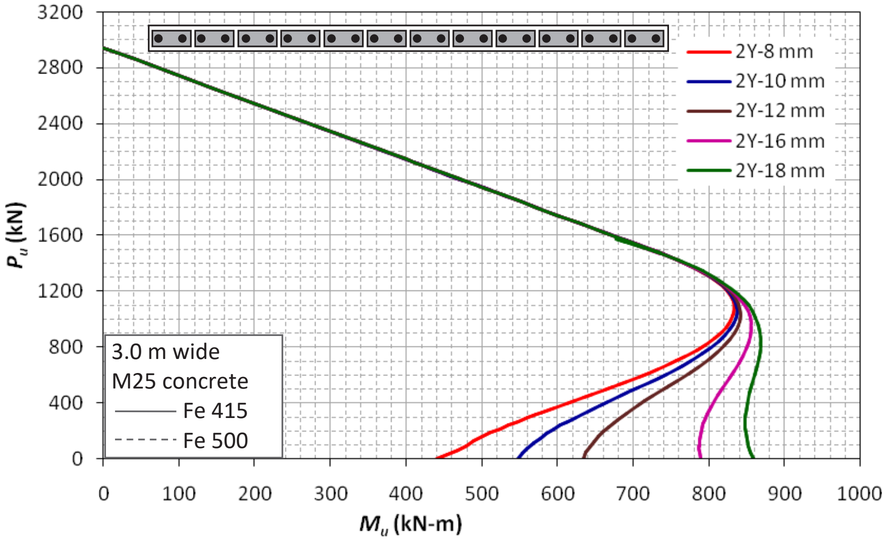


(b) Using M 25 Concrete

FIG. 45 DESIGN P_u–M_u PLOTS FOR 2.75 M WIDE GFRG PANEL WITH TWO REINFORCING BARS IN EACH CAVITY

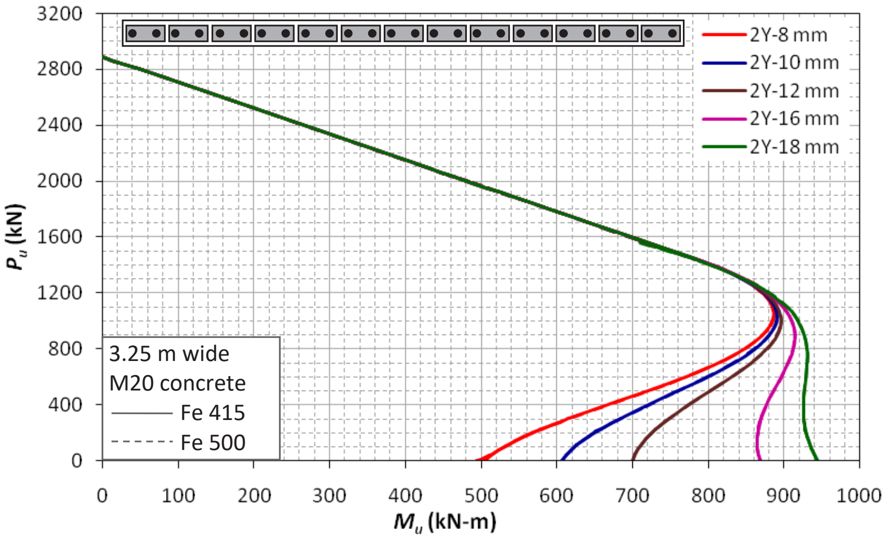


(a) Using M 20 Concrete

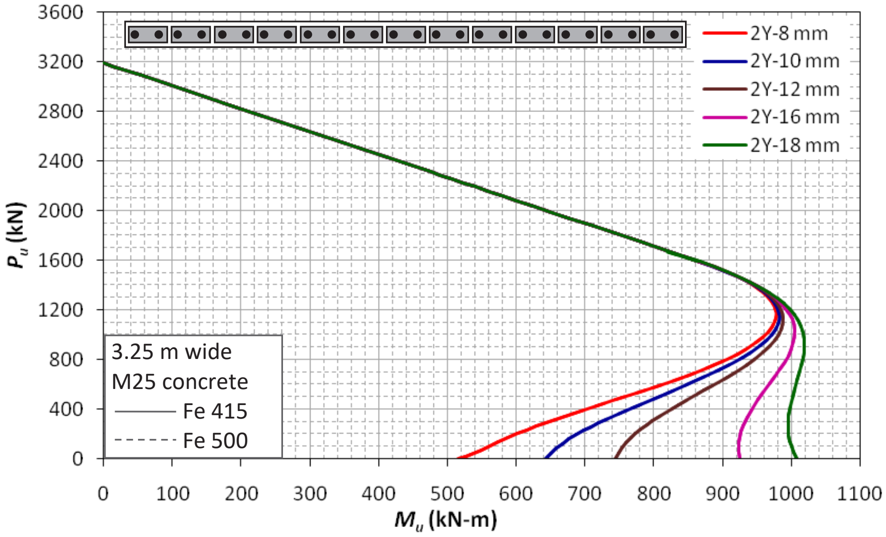


(b) Using M 25 Concrete

FIG. 46 DESIGN P_U–M_U PLOTS FOR 3.0 M WIDE GFRG PANEL WITH TWO REINFORCING BARS IN EACH CAVITY

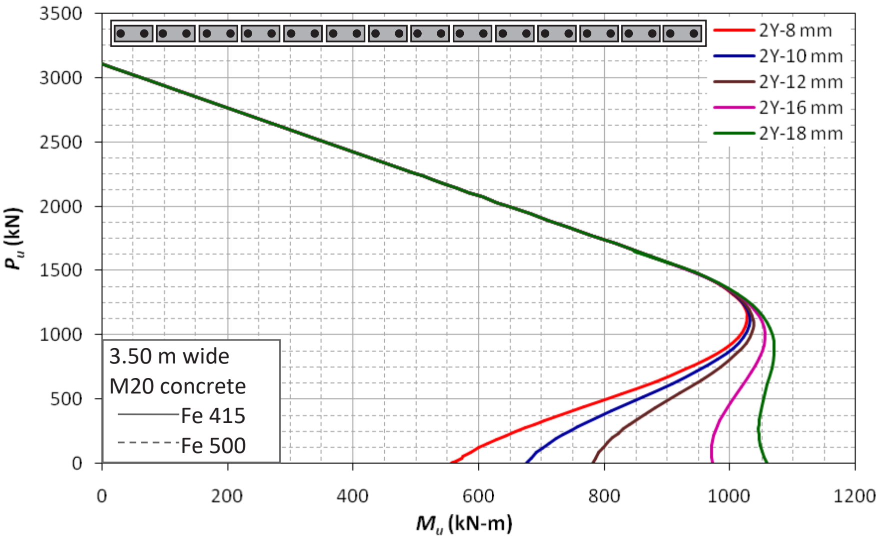


(a) Using M 20 Concrete

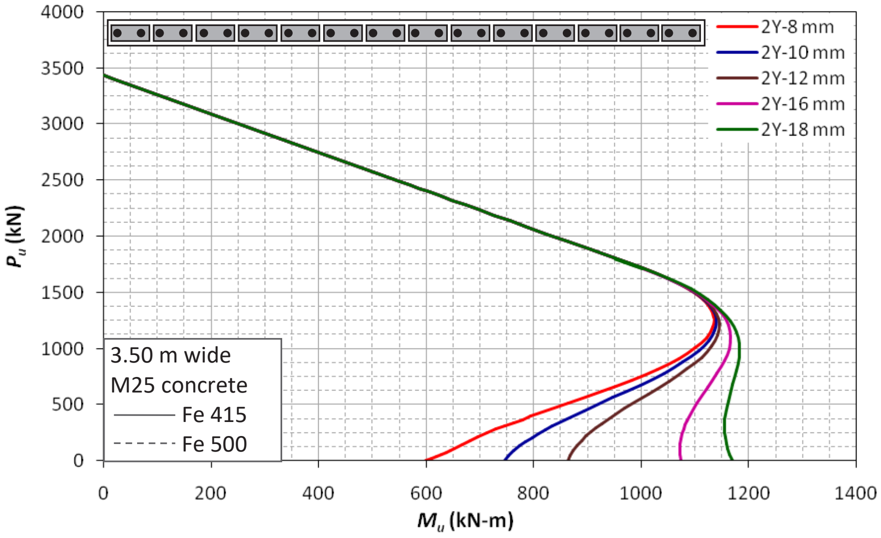


(b) Using M 25 Concrete

FIG. 47 DESIGN P_U–M_U PLOTS FOR 3.25 M WIDE GFRG PANEL WITH TWO REINFORCING BARS IN EACH CAVITY



(a) Using M 20 Concrete



(b) Using M 25 Concrete

FIG. 48 DESIGN P_u–M_u PLOTS FOR 3.50 m WIDE GFRG PANEL WITH TWO REINFORCING BARS IN EACH CAVITY

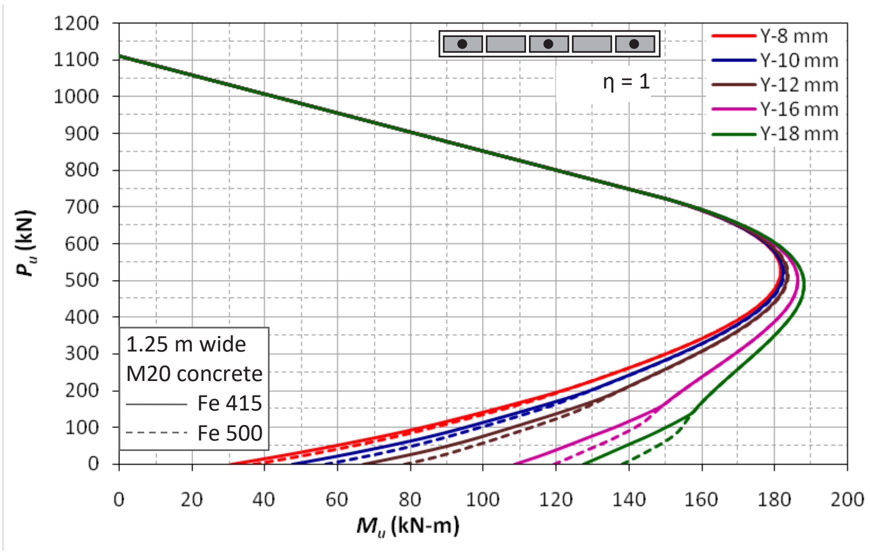


FIG. 49 DESIGN P_U–M_U PLOTS FOR 1.25 m WIDE GFRG PANEL WITH ALL CAVITIES INFILLED WITH M 20 CONCRETE AND ALTERNATIVE CAVITIES REINFORCED WITH SINGLE REINFORCING BAR

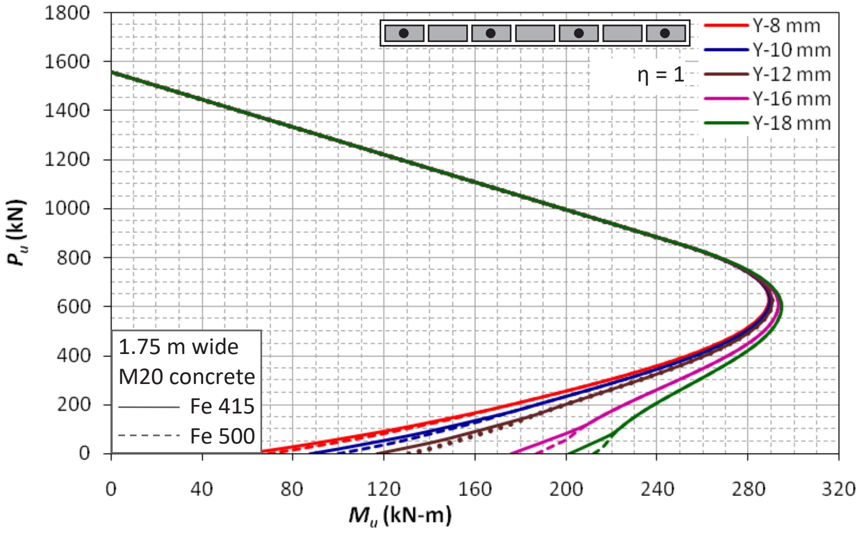


FIG. 50 DESIGN P_U–M_U PLOTS FOR 1.75 m WIDE GFRG PANEL WITH ALL CAVITIES INFILLED WITH M 20 CONCRETE AND ALTERNATIVE CAVITIES REINFORCED WITH SINGLE REINFORCING BAR

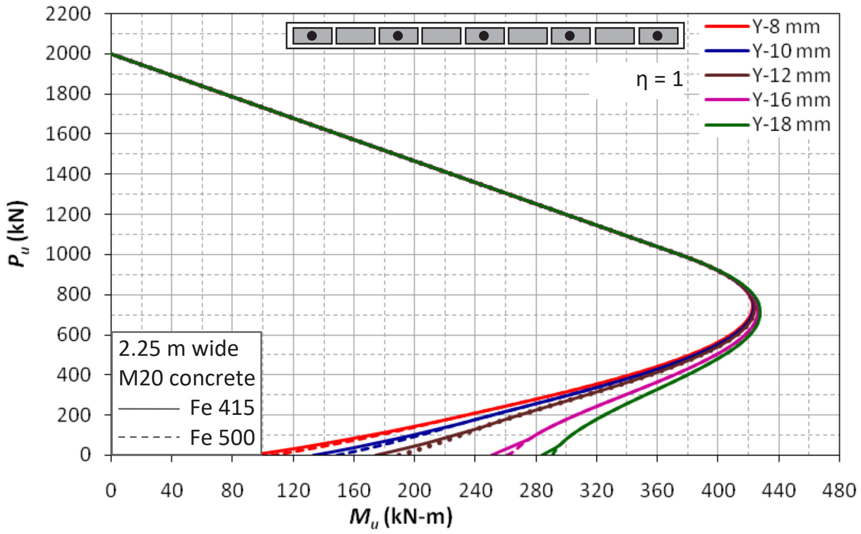


FIG. 51 DESIGN P_u–M_u PLOTS FOR 2.25 m WIDE GFRG PANEL WITH ALL CAVITIES INFILLED WITH M 20 CONCRETE AND ALTERNATIVE CAVITIES REINFORCED WITH SINGLE REINFORCING BAR

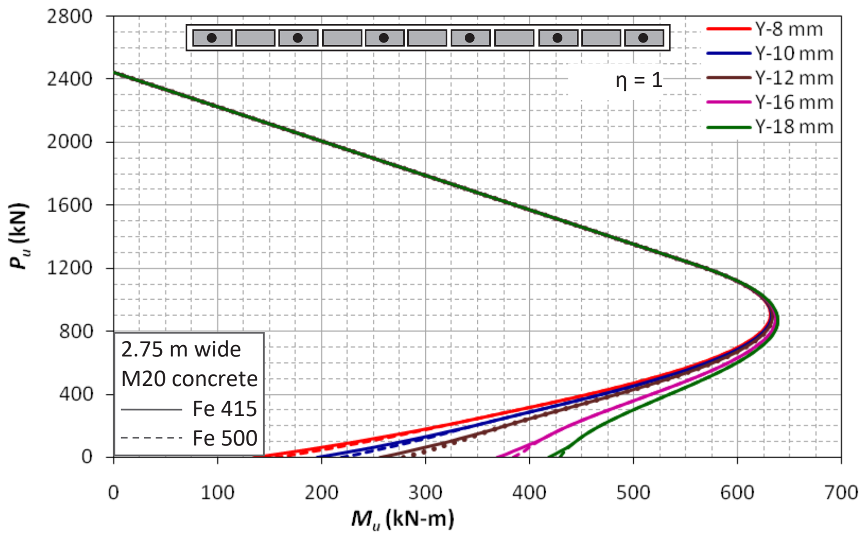


FIG. 52 DESIGN P_u–M_u PLOTS FOR 2.75 m WIDE GFRG PANEL WITH ALL CAVITIES INFILLED WITH M 20 CONCRETE AND ALTERNATIVE CAVITIES REINFORCED WITH SINGLE REINFORCING BAR

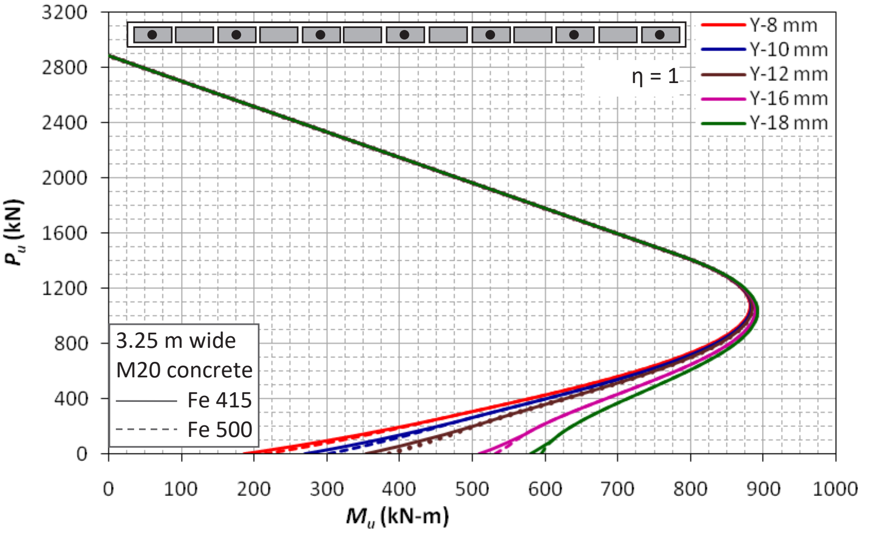


FIG. 53 DESIGN P_u–M_u PLOTS FOR 3.25 m WIDE GFRG PANEL WITH ALL CAVITIES INFILLED WITH M 20 CONCRETE AND ALTERNATIVE CAVITIES REINFORCED WITH SINGLE REINFORCING BAR

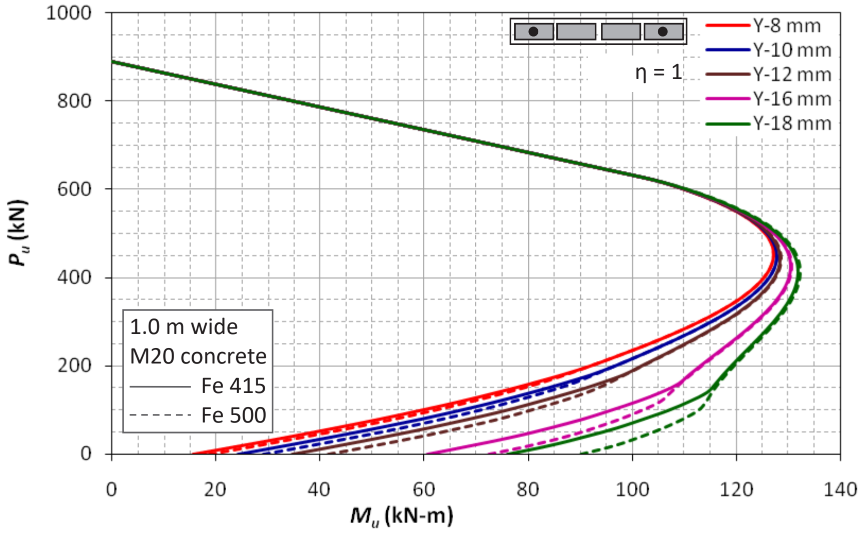


FIG. 54 DESIGN P_u–M_u PLOTS FOR 1.0 m WIDE GFRG PANEL WITH ALL CAVITIES INFILLED WITH M 20 CONCRETE AND END ALTERNATIVE CAVITIES REINFORCED WITH SINGLE REINFORCING BAR

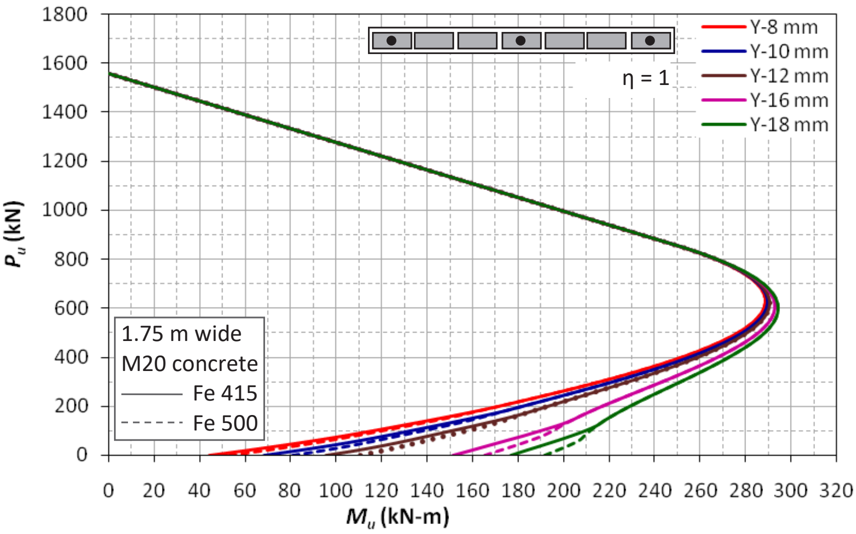


FIG. 55 DESIGN P_u–M_u PLOTS FOR 1.75 m WIDE GFRG PANEL WITH ALL CAVITIES INFILLED WITH M 20 CONCRETE AND EVERY THIRD CAVITIES REINFORCED WITH SINGLE REINFORCING BAR

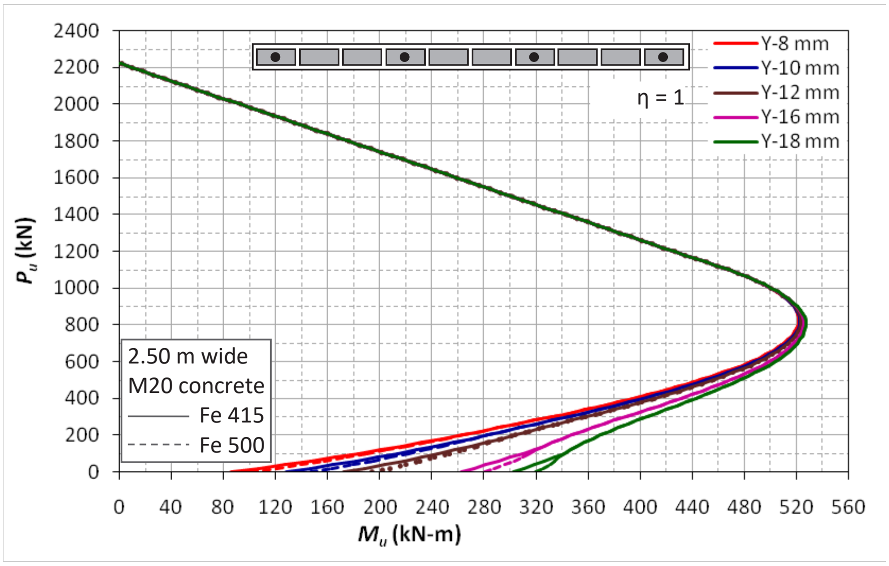


FIG. 56 DESIGN P_u–M_u PLOTS FOR 2.50 m WIDE GFRG PANEL WITH ALL CAVITIES INFILLED WITH M 20 CONCRETE AND EVERY THIRD CAVITIES REINFORCED WITH SINGLE REINFORCING BAR

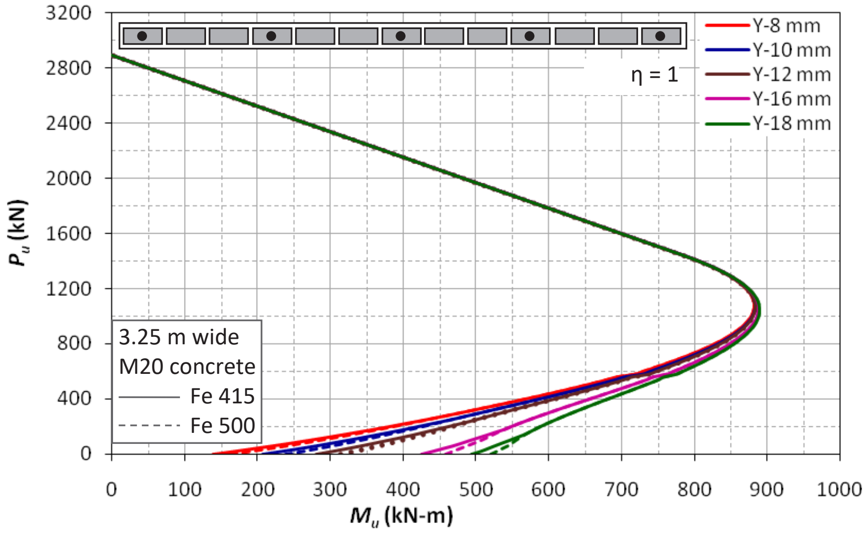


FIG. 57 DESIGN P_u–M_u PLOTS FOR 3.25 m WIDE GFRG PANEL WITH ALL CAVITIES INFILLED WITH M 20 CONCRETE AND EVERY THIRD CAVITIES REINFORCED WITH SINGLE REINFORCING BAR

ANNEX D

(*Foreword*)

COMMITTEE COMPOSITION

Building Limes and Gypsum Products Sectional Committee, CED 04

Organization	*Representative(s)*
In Personal Capacity (*B-702, Saket Dham, Sector-61, Noida - 201301*)	Dr C. L. Verma (***Chairman***)
AIMIL Ltd, New Delhi	Shri Rohitash Barua Shri K. K. V. Yasas (*Alternate*)
Archaeological Survey of India, New Delhi	Shri R. S. Jamwal
Building Materials & Technology Promotion Council, New Delhi	Shri C. N. Jha
Central Public Works Department, New Delhi	Shri Manu Amitabh Shri Divakar Agarwal (*Alternate*)
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